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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1954 WINTER MEETING ON THE PACIFIC COAST

AT

UNIVERSITY OF CALIFORNIA,
BERKELEY, CALIFORNIA

December 28, 29, and 30

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December 28, 1954 Vol. 29, No. 8

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1954 WINTER MEETING AT UNIVERSITY OF CALIFORNIA, BERKELEY, DECEMBER 28, 29, AND 30, 1954

THE **1954 Winter meeting on the Pacific Coast** of the American Physical Society will be held at the University of California, Berkeley, on Tuesday, Wednesday, and Thursday, **December 28, 29, and 30, 1954.** The Local Secretary is indebted to Professor R. T. Birge, Chairman of the Department of Physics, and particularly to a local committee under the chairmanship of Professor W. A. Nierenberg, for assuming the responsibility of planning this meeting. There are six sessions consisting almost wholly of invited papers, including one session of our Division of Electron Physics. The meeting will be notable for many reasons, one being that the number of papers shows an appreciable increase over any previous West Coast meeting. There are 28 invited papers and 166 contributed papers. This necessitates four or five parallel sessions for most of the meeting.

The attention of our members is called to the fact that this is a **joint meeting** of the American Physical Society and the American Association for the Advancement of Science (AAAS), whose meetings will be held throughout all of the same week. As a result, our Society is sponsoring a joint session with the Third Berkeley Symposium on Mathematical Statistics and Probability before our own meetings begin—Session A, Monday afternoon, at 1:30.

Registration will take place in the lobby of Le Conte Hall (in which building all of the meetings except Session A will be held). Members and guests are asked to pay a registration fee of $1.00. A telephone and message board will be available at the Registration Desk. In addition, Room 2, Le Conte Hall, will be available for informal discussions. Coffee will be served during sessions in the seminar room, 375 Le Conte Hall, and Room 385 will have a telephone for the convenience of the Society. Room 385 may be used by prospective employers for interviewing.

The **dinner** of the American Physical Society (in which Section B of the AAAS and Sigma Pi Sigma take part) will be held on Thursday evening at 7:30 at the Men's Faculty Club. The price will be $2.00 per person, and the tickets for the dinner can be purchased at the Registration Desk at the time of registration. It should be mentioned that the number of places available is strictly limited by the size of the Club and, what with the anticipated size of the meetings, there may not be room for everyone who would like to attend. The presiding officer at the dinner will be A. C. Helmholz, and the principal speaker will be R. T. Birge, Vice President of the Society.

An open **luncheon meeting,** sponsored by the Berkeley branch and the Stanford Chapter of the Federation of American Scientists, will be held on Wednesday, December 29, at the cafeteria on the Berkeley campus. Details will be posted at the meeting. All interested persons are invited.

Features of the AAAS Meeting. Two of our members will play roles of particular prominence in the meeting of the AAAS. E. U. Condon will deliver his Retiring Presidential Address, entitled "A Half Century of Quantum Physics" in Wheeler Hall on Tuesday evening at eight. E. M. McMillan will give the Annual Address of the Society of the Sigma Xi, entitled "High Energy Physics," in the same place on Wednesday evening at eight.

The AAAS desires us to announce also the following events: Presidential Reception in the Stephens Union Club Rooms on Tuesday evening beginning at nine; Biologists' Smoker, on the terrace of the Hearst Gymnasium for Women, from 8:30 to 11 on Thursday evening. Registration for the AAAS will take place in the Gymnasium for Men, where also will be found the AAAS Annual Exposition of Science and Industry, the AAAS Science Theater

("showing latest foreign and domestic films"), and the AAAS Visible Directory of Registrants.

The **Radiation Laboratory of the University of California** will do us the favor of arranging special tours of its great laboratories—one each afternoon during the meeting proper. Those who will be going must indicate their wish, and the afternoon of their choice, at the Registration Desk.

Informal tours of the Bay Area are planned by the wives of the faculty of the Department of Physics and of the members of the Radiation Laboratory. For these also, arrangements to take part must be made at the Registration Desk. No other entertainment is planned by the Local Committee; the attractions of the Bay Area are so numerous and great that competition would be doomed to failure in advance.

Rooms in hotels must be booked in a special way, for the AAAS has reserved all of the space presently available in the Bay Area. All requests for rooms must be made by writing to the Convention Bureau of the Berkeley Chamber of Commerce, Berkeley, California, with a five-dollar deposit per person, and a specific statement about the kind of accommodation wanted and the times of arrival and departure. It may very well be that many of our members will have to share double rooms.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts of these are received not later than Monday December 20 at the office of the Local Secretary for the Pacific Coast (the address below). It is intended to prepare mimeographed sheets giving the titles and the speakers for such papers as may be accepted and to distribute them at the registration desk. The abstracts will not be published. The papers that are accepted will be presented at Session V on Thursday afternoon.

Prospective meetings of the Society are listed on page 5 of this Bulletin.

The abstracts in this Bulletin will be republished, exactly as they now stand, in an early issue of *The Physical Review*. Errata will be published on an adjacent page if received not later than Friday, January 14, 1955, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "Instead of . . . read . . ." Do not add anything.

J. KAPLAN, *Local Secretary for the Pacific Coast*,
University of California,
Los Angeles 24, Calif.

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1954–1955

I. Meetings east of the Rockies and in Mexico

Place	*Meeting dates*	*Deadline date*
Chicago	November 26–27, 1954	past
New York	January 27–29, 1955	past
Baltimore	March 17–19	January 14, 1955
Washington	April 28–30	February 18
Toronto	June 22–24	not decided
Mexico City	about September 1	not decided

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meeting until the deadline date of the previous meeting is past.

II. Meeting west of the Rockies

Berkeley	December 28–30, 1954	past

RULES IMPOSED ON ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

EPITOME OF THE 1954 BERKELEY MEETING

(Personal names are those of invited speakers.)

MONDAY

1:30 A. Wiener, Kac, Montroll. 145 Dwinelle Hall.

TUESDAY

10:00 B. Shutt, Anderson, Lagarrigue, Gell-Mann. Le Conte 310.

10:00 C. Contributed papers. Le Conte 4.

10:00 D. Contributed papers. Le Conte 3.

10:00 E. Contributed papers. Le Conte 1.

2:00 F. Christy, Karplus and Ruderman, Rosenbluth and Rosenbluth, Johnson and Teller. Le Conte 1.

2:00 G. Miller. Contributed papers. Le Conte 4.

2:00 H. Contributed papers. Le Conte 3.

2:00 I. Contributed papers. Le Conte 310.

WEDNESDAY

9:00 J. Richardson, Green, Cork, Panofsky, Livingston. Le Conte 310.

2:30 K. Marshall, Sutton, Chamberlain. Contributed papers. Le Conte 310.

2:30 L. Contributed papers. Le Conte 4.

2:30 M. Contributed papers. Le Conte 1.

THURSDAY

9:00 N. Kip, Slichter, Hutchison, Pake. Le Conte 310.

9:00 O. Zernike. Contributed papers. Le Conte 3.

9:00 P. Contributed papers. Le Conte 4.

9:00 Q. Hofstadter. Contributed papers. Le Conte 1.

1:30 R. Garrett, Alpert, Bracewell, Kaplan. Le Conte 310.

1:30 S. Contributed papers. Le Conte 4.

1:30 T. Contributed papers. Le Conte 1.

1:30 U. Wildhack. Contributed papers. Le Conte 3.

1:30 V. Post-deadline papers, if any. Le Conte 2.

7:30 Banquet of the American Physical Society; Birge. Men's Faculty Club.

PROGRAMME

MONDAY AFTERNOON AT 1:30

145 Dwinelle Hall

(MINA REES, presiding)

Statistical Mechanics

Joint Session with the Third Berkeley Symposium on
Mathematical Statistics and Probability

Invited Papers

A1. Hopf-Wiener Equation System and Matrix Factorization. NORBERT WIENER, *M.I.T.* (30 min.)

A2. Foundation of Kinetic Theory of Gases. MARK KAC, *Cornell University.* (30 min.)

A3. Effect of Dimensionality on Long-Range Order in Crystals. ELLIOTT MONTROLL, *O.N.R.* (30 min.)

TUESDAY MORNING AT 10:00

310 Le Conte Hall

(R. F. BACHER presiding)

B1. High-Energy Interactions at the Cosmotron. R. P. SHUTT, *Brookhaven National Laboratory.* (30 min.)

B2. The Unstable Particles. C. D. ANDERSON, *California Institute of Technology.* (30 min.)

B3. S-Particles and Charged Heavy Particles. A. LAGARRIGUE, *Ecole Polytechnique* (Paris). (30 min.)

B4. Theoretical Views on the New Particles. M. GELL-MANN, *University of Chicago.* (30 min.)

THURSDAY MORNING AT 10:00

4 Le Conte Hall

(A. L. BENNETT, presiding)

Contributed Papers

C1. Quantitative Fluid Flow Visualization with Streaming Birefringence.* HAROLD WAYLAND, *California Institute of Technology.*—Birefringence of flow was studied in the annular space between a fixed outer and a rotating inner cylinder. With dielectric walls and well collimated light beam, quantitative measurements were possible within 0.1 mm of the wall. For an aqueous colloidal solution of bentonite, shear stress could be evaluated by birefringence measurements only when, for a given birefringence, the angle of extinction was the same in the unknown flow as in a known laminar flow. In turbulent shear flow this is not generally true. For a pure liquid, ethyl cinnamate, the angle of extinction remained at 45° to the streamlines, within experimental error, under all flow conditions obtainable; thus even in turbulent shear flow the birefringence probably arises primarily from the principal stresses. Assuming birefringence proportional to mean shear stress permits construction of a velocity profile across the gap, yielding the correct value of velocity of moving wall within limits of experimental error. Thus in two-dimensional shear flow one can measure the mean shear stress by means of streaming birefringence of a pure liquid.

* This work was carried on at the Centre de Recherche sur les Macromolecules of the CNRS at Strasbourg, France, with the aid of a fellowship of the John Simon Guggenheim Memorial Foundation.

C2. Effects of Attenuating Materials on Detonation Induction Distances in Gases.* MARJORIE W. EVANS, FRANK I. GIVEN, AND WILLIAM E. RICHESON, JR., *Stanford Research Institute.*—Detonation induction distance, x_d, is the distance from ignition point to beginning of detonation in a detonable gas. It varies with composition of gas, method of ignition, and pressure. Theory predicts that it depends upon the distance required to form a precompression shock wave of strength comparable to that of the detonation wave. Absorption of precompression waves at the walls of a cylindrical tube should lead to delay in formation of the detonation wave, or with sufficient absorption to complete suppression. The validity of this concept was tested using a stoichiometric H_2-O_2 mixture at initial pressure of 1 atmosphere, with spark ignition. The value of x_d was established in a smooth-walled steel tube of 2-inch inside diameter, and was then determined for tubes of similar diameter but with porous sintered bronze walls. Results were obtained for several thicknesses and porosities of wall material, the acoustic properties of which were known. Results showed that attenuating wall materials had a pronounced effect, more than doubling x_d in some instances. It was larger for 1-inch than for ½-inch thick walls, and for coarse than for fine wall material.

* This research was supported by Soundrive Engine Company, Los Angeles, California.

C3. Growth, Coalescence, and Decay of Vortices in a Jet Accompanying Pfeifentone. A. B. C. ANDERSON.—A shadowgraph system has been developed enabling one to take two successive shadowgraphs of microsecond time exposure and separated by a suitable time interval, whose magnitude may be varied at will. These shadowgraphs show the vortex train in the jet at successive instants. With this, studies of a carbon dioxide jet discharging into the atmosphere from an orifice (0.250 in. diameter and 0.093 in. thick) terminating a cylindrical resonant cavity (0.80 in. diameter and 12.0 in. long) were made. Typical results show that in flow regimes where a regular system of vortices shed from an orifice tend to coalescence downstream, a uniform train of larger and more evenly spaced vortices result. When two vortices coalesce, the downstream vortex tends to enlarge permitting the upstream vortex to move inside of the downstream vortex, leading to their coalescence. Pure tones are accompanied by a smooth and even array of vortices; complex tones by a somewhat distorted and irregular array. In one flow regime, a double train of vortices whose axes make a considerable angle with respect to each other, emerges from the orifice. Each train contains an alternate set of vortices shed by the orifice. The plane made by the two axes of the two trains may remain fixed or may rotate in space about the axis of the orifice.

C4. I. Shock Front Structure in Argon. JOHN W. BOND, JR., *Los Alamos Scientific Laboratory.*—One-dimensional steady-state shocks in argon of such strength that one degree of ionization is of importance are considered. The equilibrium region behind the shock front is determined by assuming the ideal-gas equation of state and using the Saha equation. The equilibrium conditions are specified by the ordinary shock equations. The non-equilibrium region which defines the shock front may be considered in two parts. The first part is that in which the translational degrees of freedom of the gas atoms are first excited and then become equilibrized. If the "local" temperature at which translational equilibrium is achieved is sufficiently high, energy will be transferred to other degrees of freedom which, in the case of argon, are those of electronic excitation and ionization. The relaxation time for complete thermal equilibrium to be reached is determined by consideration of the individual atomic interactions that take place. Finally, recombination of the electrons and the ions is treated by a method of detailed balancing. Thus the luminous region behind the shock front is preceded by a high-temperature region whose width decreases with increasing shock velocity.

C5. Detonation in Gas at Low Pressure. ARTHUR L. BENNETT AND HENRY W. WEDAA, *U. S. Naval Ordnance Test Station.*—A tube with driver section 97 cm long and an experimental section 444 cm long was used. The driver and 215 cm of the experimental section are 12 cm in diameter. A smooth transition section 46 cm long leads to a 10-cm square section 183 cm long fitted with windows. Detonation in the experimental section is initiated by spark ignition of $C_2H_2+O_2$ and ensuing detonation in the driver section. The driver is separated from the experimental section by a zip-tape diaphragm so that the initial pressures may be different. Detonation velocity is determined by CRO recording, at 1.5×10^5 cm/sec, of the pulses from accurately located ionization probes throughout the experimental section. For $2H_2+O_2$ the average velocity over the last 110 cm in 10^5 cm/sec (for the pressure in mm Hg) is: 2.82(400); 2.72(100); 2.65(50); 2.55(20). The observed velocities show no appreciable dependence on the ratio of initial driver pressure to that of hydrogen-oxygen over the limited ratio explored (0.42 to 2.5 for various experiments). The light at 46 cm from the end collimated by slits $\frac{3}{8}$ mm wide 3 to 25 mm long (175 mm separation) was measured by an *S*4 photomultiplier and high speed CRO. At 400 mm pressure the light rises immediately to a peak, then falls about 25 percent within 10 μsec, then decays another 20 percent over the 150 μsec recorded. At lower initial pressures, the rise becomes less steep, about 2 μsec at 50 mm, 5 μsec at 20 mm, and 7 μsec at 10 mm.

C6. Shock Waves in Air Produced by Waves in a Plate. WILLIAM A. ALLEN, JOE M. MAPES, AND EARLE B. MAYFIELD, *U. S. Naval Ordnance Test Station.*—A shadowgraphic technique has been used to measure surface motion of a series of steel plates while they deform under impact caused by ½-in. diameter steel cylinders fired into their back surfaces at about 3000 ft/sec. Shadowgraphs show two air shock waves separated about 3 μsec in time. Extrapolation of the air shocks back into the metal indicates that the second wave is associated with a disturbance that travels through steel at the same velocity as the initial longitudinal sound wave. This second disturbance appears associated with the actual plastic deformation of the free surface.

C7. Velocity of Explosively-Induced Shock in Steel. SAMUEL KATZ, *Stanford Research Institute.*—The velocity of explosively induced shock in steel has been measured by a new method. The test specimen is a rectangular steel plate with the two large surfaces covered with uniform layers of *C*-3 explosive and initiated at diagonally opposite edges. The two shocks generated in the steel collide at normal incidence and produce severe shock twinning and other grain deformation in a sharply defined, narrow zone whose width is related to the explosive thickness. The shock velocity is given by $v_s=v_e \sin d$, where d is the angle between the deformed zone and the loaded surface, and v_e is the detonation velocity. $v_s=4.93\pm0.13$ mm/μsec for mild steel, and 4.5 mm/μsec for 18-8 stainless steel. These values compare with those of Pack *et al.*[1] of 5.24 mm/μsec and of Allen[2] of 4.6 mm/μsec, both for mild steel. The hydrodynamic theory,[3] based on an extrapolation of Bridgman's data for an incident explosive pressure of 0.17 megabars, particle velocity 0.163 mm/μsec, and initial density 1.6 g/cm³, predicts a shock velocity in iron of 5.2 mm/μsec.

[1] Pack, Evans, and James, Proc. Phys. Soc. (London) **60**, 1 (1948).
[2] W. A. Allen, J. Appl. Phys. **24**, 1180 (1953).
[3] G. E. Duvall (private communication).

TUESDAY MORNING AT 10:00

3 Le Conte Hall

(V. F. LENZEN, presiding)

Contributed Papers

D1. On the Scattering of Electromagnetic Waves by a Bounded Lattice of Parallel Cylinders,* V. TWERSKY, *Sylvania Electric Products Inc.*—The two-dimensional problem of the scattering of a plane electromagnetic wave by a bounded lattice of parallel cylinders is treated. The lattice cell is a rectangle; the lattice itself is in the form of a slab of infinite length and finite thickness. Starting with a "self-consistent" representation for the field in terms of cylindrical waves, we derive expressions for the reflected, internal and transmitted waves in terms of certain sets of plane waves. The amplitudes and propagation coefficients of these plane waves are given by certain algebraic equations. The result is applied to determine the conditions for perfect reflection and maximum transmission (or equivalently, to derive expressions for the centers and widths of the stopping and pass bands), and to the artificial dielectric. The present results are either generalizations of, or equivalent to, certain results obtained originally by Ewald, Darwin, Laue, or Kohler. However, the present derivation, which is based on the boundary value problem of the bounded array, allows for more careful consideration of certain features; e.g., Darwin's postulated equations are here derived on the basis of Maxwell's equations subject to certain restrictions, the existence of a "medium" (with or withouts sharp boundaries) is not assumed, etc.

* Work supported by Signal Corps contract.

D2. A Modified Holtzmark Distribution. S. GASIOROWICZ, M. NEUMAN, AND R. RIDDELL, JR., *University of California, Berkeley.*—The probability distribution of the force due to a random distribution of particles generating a Newtonian potential (the so-called Holtzmark distribution) is of considerable importance in astrophysical applications.[1] One of the difficulties encountered in working with this distribution is that moments, beginning with the second one, do not exist. The divergence of these moments is a reflection of the singularity of the potential at the origin, i.e., there is no mechanism for preventing a particle from getting close to the origin. Clearly the nearest neighbors call for a more careful dynamical treatment, where the correlations are not disregarded. A distribution, excluding N nearest neighbors from statistical consideration, has been derived. Its characteristic function is given by

$$\psi^{(N)}(k)=\frac{1}{\Gamma(N)}\int d\bar{n}(r)[\bar{n}(r)]^{N-1}\times\exp\left\{\int_r^\infty d\bar{n}(r')(e^{-ik\cdot F(r')}-1)-\bar{n}(r)\right\}$$

where $F(r')$ is the force at r' and $d\bar{n}(r')$ the average number of particles in a volume d^3r. This distribution yields $(N+1)$ finite moments. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] S. Chandrasekhar, Revs. Modern Phys. **15**, 1 (1943).

D3. On Dynamical Friction. R. RIDDELL, JR., M. NEUMAN, AND S. GASIOROWICZ, *University of California, Berkeley.*—This dynamical friction may be defined as the expectation value of the force acting on a particle which moves in a field of force due to other particles.[1] This quantity has been studied in two ways: (i) a hydrodynamical approach in which the modification of the distribution function of a system due to the introduction of a test particle moving with a fixed velocity has been investigated under the assumption of small deviations from equilibrium, and (ii) a statistical approach using the modified Holtzmark distribution, for which second moments exist has been investigated. Here a uniform density was assumed and $\langle F(Z(t))_{Av}\rangle$, where $Z(t)$ is the orbit subject to the (fluctuating) force, was expanded. Explicit expressions for the coefficient of dynamical friction were obtained in the limit of high and low densities. The two approaches serve to complement each other in that the first seems more suited to long relaxation times, whereas the expansion used in the statistical approach appears most valid if these times are short. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. Kirkwood, J. Chem. Phys. **14**, 180 (1946).

D4. Apparent Limit of Convergence of the Perturbation Series Solution for the Free Undamped Duffing Equation with Hardening Spring. JOHN C. BURGESS, *Stanford, California.*—The exact solution of the equation

$$\ddot{q}+\kappa^2(q+\mu^2q^3)=0,\quad \mu^2>0 \tag{1}$$

has been given by Weigand* in terms of a complete elliptic integral of the first kind. This solution can be expanded in a power series in the dimensionless maximum displacement $\bar{Q}_m\equiv Q_m(\frac{3}{4}\mu^2)^{\frac{1}{2}}$,

$$\eta^2=1+\bar{Q}_m^2-\frac{\bar{Q}_m^4}{24}+\frac{\bar{Q}_m^6}{24}-\cdots,\quad \bar{Q}_m^2>0.75, \tag{2}$$

where Q_m is the maximum value of q and $\eta\equiv\omega/\kappa$, ω being the circular frequency of the motion. Solution of (1) by the perturbation method yields a power series in $\bar{Q}_m$ that is identical to (2) in the first four terms, the extent to which both series were evaluated, but does not provide a limit of convergence. It is usual to state only that the perturbation parameter must be "small enough." Comparison of the two series suggests that the limit of convergence of the perturbation series solution for (1) is $\bar{Q}_m^2=0.75$.

* A. Weigand, "Die Berechnung freier nichtlinearer Schwingungen mit Hilfe der elliptischen Functionen," Forschung, Bd. **12**, No. 6, 274–284 (1941).

D5. Integral Equation Solution of Space-Charge Wave Propagation. PHILIP PARZEN, *The Johns Hopkins University.*—Previous solutions[1] of the propagation of space-charge waves in a drift tube with infinite longitudinal magnetic focusing field result in a complicated transcendental equation for the propagation constant, which can be solved only numerically. An integral equation method is given for obtaining approximate closed expressions for the propagation constant. For the important practical case where the ratio of drift tube radius to beam radius is infinite, using Ramo's notation,

$$\left(\frac{T}{\gamma_0}\right)^2=\frac{2}{(\gamma_0 a)^2}\frac{1}{I_0K_0+I_1K_1},$$

where I and K are modified Bessel functions of argument $\gamma_0 a$. This method is easily extended to the case in which the charge density and beam velocity vary across the beam. The effect of a varying velocity is to cause propagation constants of the two modes to differ from the beam wave number by different amounts.

[1] S. Ramo, Proc. Inst. Radio Engrs. **27**, 757 (1939).

D6. The Statistical Thermodynamics of Isotope Effects. I. Theory of Equilibrium Processes.* IRWIN OPPENHEIM, *National Bureau of Standards.*—A statistical mechanical theory of isotope effects on the thermodynamic properties of gases and liquids has been developed. Use has been made of the expansion of the quantum mechanical partition function in powers of $\hbar^2$ to obtain expansions of the thermodynamic properties of the type

$$G = G_{\text{classical}} + \Lambda^{*2} G_1 + \Lambda^{*4} G_2 + \cdots,$$

where Λ^* is the mean de Broglie wavelength. The results are valid in intermediate temperature ranges where the effects of statistics are not important. The differences in various thermodynamic properties of isotopes are computed with the aid of classical radial distribution functions and the computations are applicable to dense gases and liquids near the critical point. An alternative formulation in terms of the Wigner distribution function has also been derived. Results may be expressed in terms of an effective temperature defined in terms of the mean kinetic energy.

* Supported in part by the U. S. Atomic Energy Commission, Division of Research.

[1] J. G. Kirkwood, Phys. Rev. **44**, 31 (1933).

D7. Statistical Thermodynamics of Isotope Effects. II. The Equation of State of the Hydrogen Isotopes at Intermediate Densities.* ABRAHAM S. FRIEDMAN AND IRWIN OPPENHEIM, *National Bureau of Standards.*—The equation of state for a dense gas is expressed in terms of reduced thermodynamic variables. These are given in terms of a classical part and a quantum mechanical part. The latter is dependent on the quantum mechanical parameter Λ^* and the derivative, with respect to the reduced volume, of a series of integrals of the radial distribution functions.[1] A generalized table of quantum mechanical compressibility factors is obtained. Using the classical 6–12 Lennard-Jones intermolecular force constants for hydrogen,[2] the differences in the compressibility factors of the six isotopic hydrogen molecules are computed. The results for $Z_{H_2} - Z_{D_2}$ (where $Z = pV/NkT$) are in excellent agreement with the experimental values[3] over a wide temperature and density range.

* Supported in part by the U. S. Atomic Energy Commission Division of Research.

[1] See preceding abstract.
[2] White, Friedman, and Johnston, Phys. Rev. **79**, 235(A) (1950).
[3] A. S. Friedman, dissertation, Ohio State University (1950); H. L. Johnston *et al.*, MDDC—850.

D8. Polarizability of the Deuteron. B. W. DOWNS, *Stanford University.*—By means of a variation method the polarizability of the deuteron in a uniform electric field has been calculated under the assumption that the ground state of the deuteron is an S state. A trial function $\psi_0 + E\psi_1$ is used to obtain an expression for the polarization energy. $E\psi_1$ is the odd parity modification of the ground state wave function, ψ_0, introduced by the perturbing electric field, E. This expression for the polarization energy is minimized with respect to ψ_1. This process leads to a differential equation for $\psi_1 \cdot \psi_1$ and the polarizability have been calculated for two cases: the n-p interaction in the deuteron was taken to be (1), a Serber interaction and (2), a square well interaction for odd parity states. The extension of this calculation to include the deuteron D wave will be discussed. A comparison will be made with the previous work of Ramsey, *et al.*[1]

[1] Ramsey, Malenka, and Kruse, Phys. Rev. **91**, 1162 (1953).

TUESDAY MORNING AT 10:00

1 Le Conte Hall

(L. I. SCHIFF, presiding)

Contributed Papers

E1. Stars Formed by Protons of 3.2 Bev from the Bevatron. JOSEPH LANNUTTI, GERSON GOLDHABER, AND STEPHEN J. GOLDSACK, *University of California, Berkeley.*—Stacks of nuclear emulsions have been exposed to the primary beam of the Bevatron at a nominal energy of 3.2 Bev. It is estimated that most of the collimated relativistic particles in the emulsions are protons of the full energy. A summary of the statistics on 118 stars with $N_H \geq 2$ formed by such particles is as follows:

No. of prongs	2–5	6–10	11–15	16–20	21–25	>25
No. of stars	45	38	20	8	4	3

Scattering and grain density measurements have been made on 70 tracks longer than 3 mm, and with grain density less than five times minimum to determine the energy and nature of the particle. The results among tracks >1.4 minimum were: π mesons, 9; protons, 38. The corresponding number for shower particles were 14 and 5. Four shower particles were too energetic to be identified. These tracks came from 270 stars. After solid-angle corrections this corresponds to a mean production of approximately one charged π meson per interaction. This work was performed under the auspices of the U. S. Atomic Energy Commission.

E2. Energy Dependence of Photoyields of N^{17}.* D. D. REAGAN, *Stanford University.*—Yield curves of N^{17} arising from electron and x-ray bombardment have been measured for the elements O, F, Ne, Mg, and Al. N^{17} was identified by its delayed neutrons which made the measurement of low yields feasible. It is clear, in spite of the low yields, that for the more complex reactions the cross section is very broad, energy-wise, and increases in the region of 150–350 Mev.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

E3. Angular Distribution of Bremsstrahlung Photons. JOHN D. ANDERSON, ROBERT W. KENNEY, AND CHARLES A. MCDONALD, JR., *University of California, Berkeley.*—The angular distribution of photons in the full-energy bremsstrahlung spectrum from the Berkeley synchrotron has been measured with a pair spectrometer at 200-, 250-, and 300-Mev photon energy. From the 20-mil platinum target, the full widths at half maximum were observed to be 8.9 ± 0.1, 8.6 ± 0.1, and 7.7 ± 0.2 milliradians respectively. This is in gross agreement with the value 9.2 ± 0.6 milliradians obtained by Rosengren[1] from the same target at 17-Mev photon energy in the full-energy bremsstrahlung spectrum from the Berkeley synchrotron. The angular distribution from the 20-mil Pt target was found to fit very nearly an exponential with a discrepancy at the origin which may be accounted for by the finite target width. The observed distributions will be compared with the theoretical distributions of Schiff and of Lanzl and Hanson. This

work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. W. Rosengren, University of California Radiation Laboratory Report No. UCRL-1999 (1952).

E4. Photodisintegration of Deuterons by High Energy Gamma Rays. DWIGHT R. DIXON AND KENNETH C. BANDTEL. *University of California, Berkeley.*—Bremsstrahlung of 335-Mev electrons was incident on a liquid deuterium target. The protons were detected with a telescope consisting of twelve scintillation counters. Pulses from the counters were combined, delayed, presented on an oscilloscope and recorded photographically. The height of the pulse from the first counter determines the dE/dx of a particle and the number of succeeding pulses determines the range. This allows one to identify the protons and measure their energy. Correction for nuclear absorption and scattering of protons has been determined experimentally using proton beams of various energies from the 184-in. cyclotron. Cross sections have been measured at laboratory angles of 49°, 75°, 106°, and 141° and at nine energies ranging from 136 Mev to 292 Mev with statistical errors of about ten percent. Results are consistent with those from Cornell University, Illinois Institute of Technology and California Institute of Technology. This work was performed under the auspices of the U. S. Atomic Energy Commission.

E5. Analysis of High-Energy Photons from the Cyclotron Target. HARLAN SHAW, DAVID COHEN, BURTON J. MOYER, AND CHARLES WADDELL, *University of California, Berkeley.*—Pair spectrometer techniques have improved considerably over those employed in earlier data,[1] allowing more clear answers to be given on the spectra contributed by proton bremsstrahlung and by π^0 decay. In particular, the symmetry properties of the total π^0 radiation may be subjected to closer scrutiny in order to show the presence or absence of other radiative processes in observable amounts. Characteristics of the bremsstrahlung radiation offer information concerning the nature of the collisions of high-energy protons with nuclei. The degree to which the nucleus may act as an integral unit in these collisions, as distinguished from a swarm of nucleons, enters into the interpretations of the bremsstrahlung spectra. A few instrumental features will be described. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] W. E. Crandall and B. J. Moyer, Phys. Rev. **92**, 749 (1953).

E6. Interaction of 95-Mev Protons with He^4.* J. M. TEEM,† W. SELOVE, AND U. E. KRUSE,‡ *Harvard University.*—The external proton beam of the Harvard cyclotron was used to bombard a liquid helium target, and the energy spectra of protons and deuterons scattered in the interaction were observed with a scintillation counter telescope by measuring simultaneously their range and specific ionization. The differential cross section for elastic scattering was measured from the region of the nuclear-Coulomb interference into the backward hemisphere. Notably, the results fail to show the characteristic diffraction minimum observed for lower incident energies or with heavier target nuclei, indicating the high transparency of He^4 for protons of this energy. The angular distribution of the deuterons from the reaction $He^4(p,d)He^3$ was also studied, and these results analyzed in terms of "pick-up" theory[1] to yield information concerning the momentum density function for a neutron in He^4. Inelastic proton spectra were measured at several angles and will be discussed.

* Assisted by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† Present address, California Institute of Technology.
‡ Present address, The University of Chicago.
[1] G. F. Chew and M. L. Goldberger, Phys. Rev. **77**, 470 (1950).

E7. Elastic and Inelastic Scattering of 90-Mev Neutrons by Deuterons. LEROY KERTH AND BYRON L. YOUTZ. *University of California, Berkeley.*—The angular distribution of the cross section for the elastic scattering of 90-Mev neutrons by deuterons has been measured, using counters to identify the particles by dE/dx and energy. Comparison with the data of Stern and Bloom[1] (for elastic scattering of protons by deuterons) shows agreement indicating the charge symmetry of nuclear forces. Comparison with calculations of Chew[2] and of Horie *et al.*[3] shows qualitative agreement. The pseudo elastic scattering of neutrons by the bound protons of the deuteron has also been investigated. The data is in disagreement with the calculations of Chew[4] but is in agreement with the data of Hadley[5] at 270 Mev. This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Stern, UCRL-2236; Bloom, UCRL-2237.
[2] Chew, Phys. Rev. **74**, 809 (1948).
[3] Horie, Tamura, and Yoshida, Progr. Theoret. Phys. **8**, 341 (1952).
[4] Chew, Phys. Rev. **84**, 710 (1951).
[5] Hadley, UCRL-1542 (1951).

E8. The Production of High Energy Neutrons and Deuterons from the Stripping of Helium. WARREN HECKROTTE, *University of California, Berkeley.*—The differential cross sections for the production of high-energy neutrons and deuterons from the interaction of 490-Mev helium nuclei with heavier target nuclei have been previously measured at this laboratory.[1] The production of neutrons from the He^3 results from the stripping off of one or both of the protons of He^3. One would not, however, expect the two protons to be stripped off simultaneously, so that one need consider the effect of only one proton being stripped off. In calculating the differential cross sections it is necessary to include the interaction between the neutron and the remaining proton after the stripping event. Because of the virtual level of the singlet n-p state, the effect of this interaction reduces substantially the width of momentum distribution of the neutron from what would be obtained by neglecting this interaction. The calculation for the deuteron production is similar except that the interaction between the neutron and proton leads to binding. The calculated and experimental results will be compared. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Schecter, Crandall, Millburn, and Ise, University of California Radiation Laboratory Report 2685.

E9. Interactions of 380-Mev Alpha Particles in Ilford G.5 Emulsion. DORA F. SHERMAN, *Radiation Laboratory, University of California, Berkeley.*—The study of stars produced by α particles in nuclear research emulsion begun by Eugene Gardner[1] has been extended to α particles of 380-Mev. Ilford G.5 emulsion has been used. The mean free path for star production is 18.1 ± 1 cm. The frequency distribution of the number of prongs per star is given in the table:

Number of prongs	1	2	3	4	5	6	7	8
Percent	2.6%	36.3	23.2	18.7	9.2	7.1	2.1	0.8

The most interesting feature of these stars is the frequent occurrence of fast singly charged particles which usually emerge at a small angle to the forward direction. Of these stars, 40.5 percent have one such grey prong, 19.8 percent have two, and 4.9 percent have three, in addition to black prongs. About one-eighth of the stars consist entirely of fast single charged particles. This includes all the one-prong stars in the table, 18 percent of the two-prong stars, and 10 percent of the three-prong stars. The above data were obtained by area scanning. An efficiency check was made by scanning along the track. In neither case were any "zero-prong" stars observed. Observation of the number of stars with a prong of range less than 50 microns, permits placement of a lower limit of 20 percent on the number of events occurring in light nuclei. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Eugene Gardner, Phys. Rev. 75, 379 (1949).

TUESDAY AFTERNOON AT 2:00

1 Le Conte Hall

(E. TELLER, presiding)

Theoretical Physics

Invited Papers

F1. Reactions and Models of Light Nuclei. R. F. CHRISTY, *California Institute of Technology.* (30 min.)

F2. Some Implications of Causality for Scattering. R. KARPLUS AND M. A. RUDERMAN, *University of California, Berkeley.* (30 min.)

F3. Application of the Monte Carlo Method to the Theory of Liquids. A. W. ROSENBLUTH AND M. N. ROSENBLUTH, *Los Alamos Scientific Laboratory* (at present on leave to the Radiation Laboratory, Berkeley). (45 min.)

F4. On the Classical Field Theory of Nuclear Forces. M. H. JOHNSON, *Lockheed Research Laboratory,* AND E. TELLER, *University of California, Berkeley.* (45 min.)

TUESDAY AFTERNOON AT 2:00

4 Le Conte Hall

(G. SEABORG, presiding)

Invited Paper

G1. Radio Chemical Studies on Nuclear Reactions at the Cosmotron. J. M. MILLER, *Department of Chemistry, Columbia University, and Brookhaven National Laboratory.* (30 min.)

Contributed Papers

G2. Long-Lived Radioactive Aluminum-26. J. R. SIMANTON, R. A. RIGHTMIRE, A. L. LONG, AND T. P. KOHMAN, *Carnegie Institute of Technology.*—There is theoretical[1] and experimental[2] evidence for a level in Al^{26} below the 6-second 0+ level. The ground state apparently lies 4.0 Mev above that of Mg^{26}, probably has a 5+ configuration, and evidently is very long-lived. Weak β and γ radioactivity has been observed in aluminum carrier isolated from magnesium bombarded by deuterons, the specific activity remaining constant through numerous chemical separations. The most prominent radiations correspond to positron emission to the 1.83-Mev first excited state of Mg^{26}. The yield indicates a half-life of $\sim 10^6$ years, consistent with a $5+ \rightarrow 2+$ (second-forbidden) transition.

[1] R. W. King and D. C. Peaslee, Phys. Rev. **90**, 1001 (1953); P. Stähelin, Helv. Phys. Acta **26**, 691 (1953); Phys. Rev. **92**, 1076 (1953); S. A. Moszkowski and D. C. Peaslee, Phys. Rev. **93**, 455 (1954).
[2] Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953); Haslam, Roberts, and Robb, Can. J. Phys. **32**, 361 (1954); Kluyver, van der Leun, and Endt, Phys. Rev. **94**, 1795 (1954); C. P. Browne, Phys. Rev. **95**, 860 (1954).

G3. Radiations of Ba^{128}–Cs^{128}. J. M. HOLLANDER AND M. I. KALKSTEIN, *Radiation Laboratory, University of California, Berkeley.*—The chain Ba^{128}–Cs^{128} has been prepared in the 184-inch cyclotron by the reaction $Cs^{133}(p,6n)Ba^{128}$, and their radiations have been studied with a 50-channel scintillation spectrometer, a scintillation coincidence spectrometer, and a magnetic lens beta-ray spectrometer. Gamma rays of energy 440 kev and 980 kev have been observed belonging to the decay of Cs^{128}. A 270-kev gamma ray is observed in the decay of Ba^{128}. The beta-ray spectrometer data indicate three positron groups of end-point energies 3.0, 2.5, and 1.5 Mev with relative abundances of 7:3:0.3, respectively. These belong to the decay of Cs^{128} which decays mainly by positron emission with a ratio of β^+/EC of 3:1. Coincidence data will also be given and a decay scheme presented. This work was performed under the auspices of the U. S. Atomic Energy Commission.

G4. Gamma Rays in the Alpha Decay of 100^{254}. F. ASARO, F. STEPHENS, AND I. PERLMAN, *University of California, Berkeley.*—By alpha particle-gamma ray coincidence measurements, L x-rays and gamma rays of 42 ± 4([2 ± 1]$\times10^{-2}$ percent) and 94 ± 2 kev ([4.4 ± 1]$\times10^{-2}$ percent) were observed in the decay of 100^{254}. The L x-rays and the 42-kev gamma ray are interpreted as the transition in the daughter nucleus from the first excited state to the ground state. The abundance of L x-rays corresponded to a 15 percent alpha particle population to the first excited state. The spin of this level is established as two, even parity, from the conversion coefficient of the 42-kev gamma ray and other criteria. The 94-kev gamma ray is interpreted as an $E2$ transition from the second to the first even spin state. Reasonable estimates of a conversion coefficient indicate that the alpha particle population to the second excited state lies between 0.3 and 0.8 percent. After correction for energy differences, the alpha particles population to the second even spin state of even-even nuclei is a maximum for thorium emitters (no values below thorium), progressively decreases to a minimum for curium and then increases progressively for californium and element 100. This behavior was qualitatively predicted in Rasmussen's treatment of spheroidal nuclei.[1] This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. O. Rasmussen, Jr., University of California Unclassified Report, UCRL 2431 (1954).

G5. Alpha Groups and Angular Correlation of Am^{243}. F. STEPHENS, J. HUMMEL, F. ASARO, AND I. PERLMAN, *University of California, Berkeley.*—Using an alpha particle spectrograph, we have continued a study of Am^{243} showing alpha groups of 5.340 (0.17 percent), 5.309 (0.16 percent), 5.267 (87.1 percent), 5.224 (11.5 percent), and 5.169 (1.1 percent) Mev. We have also examined the angular correlation between alpha particles and the prominent 75-kev gamma ray. The data were best fit by the function, $W(\theta)=1-0.11\cos^2\theta$. The anisotropy in the correlation contributed by alpha particles which do not directly populate the 75-kev level was less than 3 percent. The spins of Am^{243} and Np^{239} have been measured at 5/2[1] and 1/2,[2] respectively. If the 75-kev gamma ray, which is an $E1$[3] transition, terminates at the ground state (spin 1/2) of Np^{239}, the only spin possible for the 75-kev level permitting any angular correlation is 3/2. Furthermore the theoretical correlation for this 5/2–3/2–1/2 sequence is $W(\theta)=1-0.14\cos^2\theta$, which is in good agreement with the observed correlation. This line of reasoning is inconsistent with the spin of 2.5 ± 0.2 calculated for the 75-kev level on the basis of the alpha particle energies and the Bohr-Mottelson theory. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. Conway and R. McLaughlin, Phys. Rev. **94**, 498 (1954).
[2] J. Conway and R. McLaughlin, Phys. Rev. (to be published) (1954).
[3] F. Asaro and I. Perlman, Phys. Rev. **93**, 1423 (1954).

G6. The Alpha Decay of Pa^{231}. JOHN P. HUMMEL, F. ASARO, AND I. PERLMAN, *University of California, Berkeley.*—Using an alpha-particle spectrograph we have studied the alpha groups of Pa^{231}. Using Rosenblum's[1] energy for the 4.938-Mev group as a standard, the following groups have been observed −5.046 Mev (8.7 percent), 5.018 (23 percent), 5.001 (28 percent), 4.938 (27 percent), 4.843 (1.5 percent), 4.724 (10 percent), 4.667 (1.4 percent), and 4.627 (0.3 percent). These groups are essentially the same as observed by Rosenblum except that the 5.018 and 5.001-Mev groups were previously reported as a single group. (We have completely resolved these groups in a high-resolution run.) Also, the lowest energy group has not previously been reported. These alpha groups lead to a somewhat revised level scheme which accommodates the 27-kev gamma seen by Riou[2] and the 48-kev gamma seen by Mouhasser and Riou.[3] Also, the conversion electron data of Falk-Vairant[4] and gamma data of Moore[5] can be fitted to these levels forming a decay scheme for this nuclide. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Rosenblum, Cotton, and Bouissieres, Compt. rend. **229**, 825 (1949).
[2] M. Riou, Compt. rend. **234**, 1157 (1952).
[3] A. Mouhasser and M. Riou, Compt. rend. **238**, 2520 (1954).
[4] P. Falk-Vairant and M. Riou, J. phys. et radium **14**, 65 (1954).
[5] R. Moore, thesis, Ohio State University, AECU-2757 (1953).

G7. Tantalum Spallation and Fission Induced by 340-Mev Protons. WALTER E. NERVIK AND GLENN T. SEABORG, *University of California, Berkeley.*—Tantalum metal has been irradiated with 340-Mev protons in the 184-in. Berkeley cyclotron. Nuclides formed as spallation and fission products were separated chemically, identified, and their formation cross sections calculated. A very broad fission peak which extends from about mass number 20 to mass number 132 is observed. The maximum fission yield occurs in the region of the nuclide Kr^{83} and analysis of a set of contour curves fitted to the data indicates that either Hf^{166} or Lu^{166} is "the most probable fissioning nucleus." Comparison of the fission data of tantalum, bismuth, and uranium under the same bombardment conditions indicates that asymmetric fission is much more probable in tantalum than in either of the other elements. The total cross section for fission of tantalum with 340-Mev protons is estimated to be 4.1 mb. In the spallation region, neutron emission is observed to be the predominant reaction. Integration under the spallation yield curve indicates that of those tantalum target nuclei which received at least enough excitation energy to reach the region of "the most probable fissioning nucleus" less than one percent undergo fission; the remainder undergo spallation reactions. This work was performed under the auspices of the U. S. Atomic Energy Commission.

G8. Fission-Spallation Competition in Heavy Elements. R. A. GLASS, R. J. CARR, J. W. COBBLE, AND G. T. SEABORG, *University of California, Berkeley.*—A study of the competition of the fission and spallation processes in excited heavy element nuclei has led to some rather unexpected observations. In the alpha-particle-induced reactions (20 to 50 Mev) in Pu^{239}, for example, the spallation product excitation functions, while giving low cross sections as anticipated, showed the same shape as those predicted for nonfissioning nuclei by the statistical model. Further, for some reactions the emission of a proton in an $(\alpha,p2n)$ reaction was found to be favored over neutron emission in a similar three- article emission $(\alpha,3n)$ reaction. The integrated fission yield curves obtained by radiochemical analysis yielded total fission cross sections and were used to fix the nuclear radius. Such well-defined spallation excitation functions can be used to elucidate some of the factors governing the fission process itself in a comparison of different nuclear types. Data obtained for the Pu^{235}, Pu^{239}, and Pu^{243} spallation yields thus indicate the effects of mass type on the fissionability of nuclei. These results also can be interpreted on the basis of a statistical model. Certain features of noncompound nuclei effects also present in these reactions will be discussed. This work was performed under the auspices of the U. S. Atomic Energy Commission.

G9. Isomeric States in the Chain $Mo^{90}\rightarrow Nb^{90}\rightarrow Zr^{90}$. H. B. MATHUR AND E. K. HYDE, *University of California, Berkeley.*—In the decay of 5.7-hour Mo^{90} three distinct isomers of the odd-odd isotope Nb^{90} are produced. Nb^{90m_1} has a half-life of 24 seconds and Nb^{91m_2} has a half-life of 10 to 20 milliseconds. The ground state of Nb^{90} is the well-known 14.6-hour activity. Study of its radiations showed a delayed transition of 2.3-Mev energy in the even-even nucleus Zr^{90}. The chemical and spectrometer evidence supporting these assignments will be discussed. This work was done under the auspices of the U. S. Atomic Energy Commission.

G10. Decay Scheme of Np^{238}*. J. O. RASMUSSEN, *University of California, Berkeley,* AND H. SLÄTIS, *The Nobel Institute of Physics, Stockholm.*—The results of beta spectroscopic studies[1–3] and scintillation counter and coincidence studies[4] on Np^{238} are analyzed. The decay gives rise to a hard beta group of 1260 kev proceeding to the 44.2-kev state and three soft beta groups populating the levels near 1 Mev. Gamma transitions of 44.2, 102.0, 927, 941, 986, and 1030 kev occur. A beta-decay scheme is proposed involving six levels of the daughter nucleus Pu^{238}, namely, the known ground rotational band levels of energies (in kev) 0, 44.2, 146.2 and a higher cluster of levels at 1030, 1073, and either 1087 or 985. The decay scheme is discussed in respect of its consistency with the strong coupling approximation of the Bohr-Mottelson unified nuclear model. In particular, it is proposed that the levels at 1030 and 1073 kev probably constitute the two lowest rotational members of the first gamma-vibrational band in the strong coupling model.

* Work performed in part under the auspices of the U. S. Atomic Energy Commission.
[1] Freedman, Jaffey, and Wagner, Phys. Rev. **79**, 410 (1950).
[2] Slätis, Rasmussen, and Atterling, Phys. Rev. **93**, 646 (1954).
[3] Rasmussen and Passell, unpublished results.
[4] Rasmussen, Stephens, Strominger, and Åström (unpublished results).

G11. Gamma Rays of Ra^{225} and Tl^{209}. I. PERLMAN, F. STEPHENS, AND F. ASARO, *University of California, Berkeley.*—We have studied the gamma spectra associated with two of the beta emitters of the Th^{229} family. Chemically separated Ra^{225} showed L x-rays and a gamma ray at 39.5 ± 2.0 kev. The L x-ray intensity gave a maximum L conversion coefficient of 1.0, clearly indicating an $E1$ transition. The half-life of the 40-kev level was shown to be less than 2×10^{-9} sec.[1] Both the singles beta spectrum and that in coincidence with the 40-kev photon showed end points at 0.32 ± 0.03 Mev. Using coincidence techniques gamma rays of Tl^{209} were identified at 0.12, 0.45, and 1.56 Mev, all of which were in coincidence with one another. Together with the beta energy of 1.99 Mev[2] this yields a total decay energy of 4.12 Mev in reasonable agreement with the calculated value 3.92 Mev.[3] Furthermore, Harvey[4] has found levels in Pb^{209} at 1.56 and 2.03 Mev (among others). The present work is in excellent agreement with these levels and indicates another around 2.13 Mev. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. Rasmussen and F. Stephens, unpublished data (1954).
[2] Wagner *et al.*, Phys. Rev. **88**, 171(A) (1952).
[3] Glass, Thompson, and Seaborg, J. Inorg. and Nucl. Chem. (to be published).
[4] J. A. Harvey, J. Can. Phys. **31**, 278 (1953).

G12. Neutron Deficient Chains of Mass 187 through 191. W. G. SMITH AND J. M. HOLLANDER, *University of California, Berkeley.*—A radiochemical study of some neutron deficient nuclides in the noble metal region has been undertaken, and several new chains identified. The method used to establish genetic relationships was that of timed chemical separations, where the parent activities are initially produced by cyclotron or linear accelerator bombardments. The following chains have been identified:

$A=191$: $Hg^{191} \xrightarrow{55\ min} Au^{191} \xrightarrow{3.0\ hr} Pt^{191} \xrightarrow{3.0\ day} Ir^{191}$
$A=189$: $Hg^{189} \xrightarrow{\sim 20\ min} Au^{189} \xrightarrow{42\ min} Pt^{189} \xrightarrow{10.5\ hr} Ir^{189} \xrightarrow{11\ day} Os^{189}$
$A=188$: $Pt^{188} \xrightarrow{10.0\ day} Ir^{188} \xrightarrow{41\ hr} Os^{188}$
$A=187$: $Au^{187} \xrightarrow{\sim 15\ min} Pt^{187} \xrightarrow{2.5\ hr} Ir^{187} \xrightarrow{14\ hr} Os^{187}$

This work was performed under the auspices of the U. S. Atomic Energy Commission.

G13. Occurrence of Technetium-98 in Nature.* EDWARD A. ALPEROVITCH† AND J. MALCOLM MILLER, *Columbia University and Brookhaven National Laboratory.*—A systematic search by neutron activation analysis for naturally occurring long-lived Tc^{98} has been undertaken. Concentrates from various minerals (columbite, yttrotantalite, thortveitite, and chromite) were irradiated in the Brookhaven pile at a thermal neutron flux of $\sim3\times10^{12}$, and examined by scintillation counting for any Tc^{99m}, formed by the (n,γ) process on Tc^{98}. The radiation and decay characteristics of Tc^{99m} (140 kev γ ray, $t_{\frac{1}{2}}=6h$) are sufficiently unique to permit unequivocal identification, provided that no other γ-emitting activities are present in appreciable amounts. Moreover, it must be ascertained that the Tc^{99m} was not formed by the process: $Mo^{98}\ n,\gamma\ Mo^{99} \xrightarrow[67h]{\beta^-} Tc^{99m}$. A chemical procedure, giving decontamination factors of $\sim10^{10}$ from rhenium, molybdenum, and most otner elements, was developed and tested. Of 12 concentrates examined thus far, seven gave positive and two gave negative results; in the three remaining cases the identification was uncertain. In most cases, the formation of the activity from molybdenum could be ruled out with sufficient certainty to leave the (n,γ) process on naturally occurring Tc^{98} as the most plausible explanation. Further work is in progress.

* Supported in part by the U. S. Atomic Energy Commission.
† Present address: University of Illinois, Urbana, Illinois.

TUESDAY AFTERNOON AT 2:00

3 Le Conte Hall

(L. B. LOEB, presiding)

Contributed Papers

H1. Emission from the Single Lattice Step of Clean Tungsten.* J. K. TROLAN, J. P. BARBOUR, E. E. MARTIN, AND W. P. DYKE, *Winfield College.*—Electron emission from the edge of the outermost atom layer of several different crystal faces on tungsten and tantalum has been observed at emitter current densities above 5×10^6 amp/cm^2. This effect appears on a field emission pattern as a high-density emission ring in the normally low current density crystal directions, (110), (211), and (100). When the emitter tip is maintained at a temperature in the range $1700°K<T<2700°K$, and for purposes of viewing the electric field is simultaneously applied in short periodic pulses, the radius of the described emission ring is seen to decrease to zero. After a period of uniformly low emission, another ring appears at the periphery of the low density region, gradually collapses, and is followed in turn by other collapsing rings spaced at nearly equal intervals of time. Through measurements of emitter electron micrographs taken before and after observation of such a series, the collapse of a ring has been associated with the dissolution of the top atom layer from the emitter tip. The ability to observe the transport of the minute amounts of material involved in a single atom layer permits measurement of the dependence of the rate of transport on temperature, radius of curvature, crystal direction, and emitter material under conditions of excellent vacuum and clean surfaces.

* This work supported in part by the Office of Naval Research.

H2. Field Emission from Rhenium: The Emission Pattern Corresponding to Hexagonal Crystal Structure.* GEORGE BARNES, *Winfield College.*—The first field emission patterns from a clean metal having the hexagonal crystal structure (rhenium) are photographed. The fabrication of rhenium field emitter needles having tip radii of the order of 5×10^{-5} cm is described, and electron microscope shadowgraphs of these emitters are shown. Smoothing of the emitter tip by heat treatment is also illustrated by shadowgraphs. Photographs taken before and at intervals during emitter heating in the final vacuum show the development of the clean rhenium field emission pattern; Miller-Bravais indices are assigned to certain of the pattern's dark "holes." The current drawn from the rhenium is proved to be the result of field emission. The rate of contamination of a rhenium emitter as evidenced

by its emission pattern is shown to be less than that for a tungsten emitter under identical vacuum conditions.

* This work supported in part by the U. S. Air Force.

H3. Electrical Stability of the T-F Emitter.* W. P. DYKE, J. P. BARBOUR, J. K. TROLAN, AND E. E. MARTIN, *Winfield College.*—Electrons are emitted from metals in the combined presence of both a high-surface electric field and an elevated cathode temperature, a process which has been called *T–F* emission.[1] Such cathodes have properties which can be useful in electronic devices;[2] however, their employment has been limited by lack of electrical stability and life. In the present work, an intermediate cathode temperature, 2000°K for tungsten, was used to stabilize the electrical performance of the *T–F* emitter during long periods of repetitive pulsed operation at useful power levels and at duty cycles up to about 0.25. Transport mechanisms, primarily evaporation and surface migration, were used to maintain a smooth clean cathode surface whose stability was established during several life tests which are described. Excessive transport, which would otherwise undesirably after the gross cathode geometry, was minimized by use of intermediate cathode temperatures and surface radii of curvature exceeding about 5×10^{-5} cm, the latter being in the range likely to be useful in practical application. The method is less useful during steady state operation since the cathode is then deformed by large electrostatic forces in the presence of thermal agitation.

* This work supported by the U. S. Air Force and the Office of Naval Research.
[1] W. W. Dolan and W. P. Dyke, Phys. Rev. **95**, 327 (1954).
[2] W. P. Dyke, (to be published).

H4. Electron Mobility in AgCl: Comparison of Experiment with Theory.* FREDERICK C. BROWN, *Reed College.*—Further results are presented on the temperature dependence of electron drift mobility in AgCl.[1] The measurements were made, using crystal counter techniques, on well annealed samples in which the range of conduction electrons was of the order of 10^{-4} cm per volt/cm of electric field strength. Composition, purity and strain of the crystals are important in determining their electronic properties. Some information bearing on these matters is had from optical data. The results for several crystals indicate that electron mobility can be fitted over a wide temperature range by an expression of the form $\mu=2.5\times10^{5}T^{-1}$. This suggests interaction of the slow electrons primarily with acoustic modes of vibration of the lattice but may be the result of a coincidence. It is possible to match experiment with the theory based on interaction with the optical modes[2] taking into account additional scattering by ionized impurity atoms. However, a fairly high concentration of ionized impurities, 10^{17} to 10^{18} atoms per cc, is required. The possibility of scattering by dislocations is considered.

* Partially supported by the Research Corporation and The National Science Foundation.
[1] F. C. Brown, Phys. Rev. **92**, 502 (1953).
[2] F. Low and D. Pines, Phys. Rev. **91**, 193 (1953).

H5. Measurements of Electron Density in Long-Lived Nitrogen Afterglows. ANDREW L. GARDNER, *University of California.**—Microwave methods utilizing the shift of resonant frequency have been used to measure the electron density at points along a system of flowing active nitrogen at pressures of a few mm Hg. The electron density, n, exhibits a decided growth and reaches its maximum more than 0.1 second after the gas has passed the exciting discharge. The magnitude of n and its rate of decay show marked dependence upon the amount of oxygen present in the nitrogen and correlate with light intensity measurements made on a similar flow system by Willey.[1] Measurements were made in which traces of nitric oxide and traces of oxygen were alternately introduced downstream from the exciting discharge. Evidence indicates the ionization of NO by metastable nitrogen molecules is a principal source of electrons. The electrons are then available for collisions in which the metastable $a'\pi g$ state of N_2 may be converted into the radiating $B^3\pi g$ state as proposed by Nicholls.[2]

* Work sponsored by Wright Air Development Center.
[1] E. J. B. Willey, J. Chem. Soc. 336 (1930).
[2] R. W. Nicholls, J. Chem. Phys. **20**, 1040 (1952).

H6. Electric Field Measurements in a Glow Discharge Using a Refined Electron Beam Technique. ROGER WARREN, *University of California, Berkeley.*—A new technique has been developed for measuring electric fields with an electron beam. The electron beam is acted upon simultaneously by both the unknown electric field and a known external transverse magnetic field. By adjusting the magnetic field for a null deflection of the beam, it is possible to determine the electric field, since then the two fields are proportional. In this way, the electric field has been measured in the cathode region of glow discharges at various pressures and currents in air, nitrogen, hydrogen, helium, and argon. Significant deviation from the previously reported linear field variations in the cathode fall have been observed. Electric fields in striations of the positive column have also been examined. Arguments in support of a proposed theory of the cathode region will be presented.

H7. Photoionization by Absorption in a Gas of Radiations from a Discharge in the Same Gas.* C. D. MAUNSELL, *University of California, Berkeley.*—Measurements have been made with a Kingdon cage space charge detector of the positive ions produced in a gas by absorption of radiation excited in a different region in the same gas through bombardment by an electron beam of known energy (0–100 volts). The apparatus was so arranged that neither electrons nor positive ions from the photon source could enter the detector. Absorption coefficients were evaluated by changing the separation between source and detector. No positive ions could be detected in hydrogen. In nitrogen the absorption coefficients corresponded to a cross section per molecule of about 4×10^{-18} cm^2, about fifteen times that observed in the ionization continuum using spectrally dispersed radiation and photographic methods.[1] Argon gave a cross section of the same order as nitrogen. Suggestions as to the processes responsible for these large values will be presented. An attempt is being made to check these observations of photoionization using a similar source but with a parallel plate ionization chamber as detector.

* This work was supported by the Office of Naval Research.
[1] Weissler, Lee, and Mohr, J. Opt. Soc. Am. **42**, 84 (1952).

H8. On Plasma Oscillations in a Static Magnetic Field.* L. WILCOX AND J. E. DRUMMOND, *Electronic Defense Laboratory, Sylvania Electric Products Inc.*—Recent work[1] in the theory of unbounded electron plasma oscillations in a static magnetic field has demonstrated, in an idealized case, the existence of frequency bands in which traveling wave solutions are forbidden at integer multiples of the cyclotron frequency. The extension of these results, based on a rigorous treatment of the Boltzmann equation, to problems more nearly representing the condition of electron plasmas in the laboratory appears to be very difficult.[2] A study of the motion of individual particles provides further insight into the origin of these bands and shows how simplified, macroscopic approaches may be modified to yield qualitative agreement with the rigorous theory. The study shows in detail that the forbidden bands result from a resonant interaction of electrons in disordered motion and space harmonics of the oscillating electric field. Finally the study shows in a semiqualitative manner that the discontinuities in the dispersion relation of Gross tend to disappear rapidly when perturbing effects such as electron drift and close Coulomb interactions are considered.

* Work carried out under U. S. Signal Corps Contract No. DA-36-039-sc-31435.
[1] E. P. Gross, Phys. Rev. **82**, 232 (1951).
[2] J. E. Drummond, L. Wilcox, Proc. Seventh Annual Gaseous Electronics Conference, New York (October, 1954).

H9. Streamers in Positive Point-to-Plane Breakdown in Air.* GILBERT G. HUDSON, *University of California, Berkeley.*—Modification of the method used by Meek and Saxe,[1] and by Amin[2] to include a second photomultiplier, which triggers the CRO, and improvement of the resolution have made it possible to study the streamers that precede the main stroke in positive point-to-plane breakdown in room air. Speeds and time variation of luminosity can be observed. For appropriate values of point radius r and gap length d, a single "set" of streamers precedes each main stroke. Each set consists of a primary streamer (10^8 cm/sec) and a secondary (average speed $\sim$1 to 5×10^7 cm/sec) which starts from the anode simultaneously with the primary. The average interval, $\bar{T}$, between the primary and the main stroke depends on r and d (as well as on overvoltage, in the case of a pulsed V). For $r=9.5$ mm and $d=1.5$ cm $\bar{T}\sim0.2$ μsec; the average *secondary* streamer-main stroke delay, $\bar{T}_s$, is about 0.1 μsec. For smaller points ($r\sim1$ mm) $\bar{T}$ may be 5 μsec, or longer. In some gaps (small r and larger d) as many as ten sets (with separations >200 μsec) precede each main stroke. Though the main stroke is difficult to study, because of the electrical pick-up resulting from it, there have been definite indications that it moves toward the anode more rapidly than 10^8 cm/sec.

* This work has been supported by the Office of Naval Research and by the Research Corp.
[1] J. M. Meek and R. F. Saxe, Nature **162**, 263 (1948).
[2] M. R. Amin, J. Appl. Phys. **25**, 358 (1954).

H10. Contact Charging between Monocrystalline Nonconductors and Metals.* P. E. WAGNER, *University of California.*—Previous data[1] on the electrostatic charge developed by fused quartz and Pyrex spheres when rolled on a Ni surface have been extended to the monocrystalline insulators SiO_2, Al_2O_3, NaCl, KCl, KBr, and KI. The alkali halides charge positively, while the oxides charge negatively. Both fused and crystalline quartz charge similarly to saturation values about ten times higher than values attained by the others. Electron transfer is believed to cause the charging and should lead to a predictable variation of saturation charge with metallic work function, for a given insulator. Experiments designed to measure this variation will be discussed.

* Research supported by the Office of Naval Research.
[1] J. W. Peterson, J. Appl. Phys. **25**, 907 (1954).

TUESDAY AFTERNOON AT 2:00

310 Le Conte Hall

(W. A. NIERENBERG, presiding)

Contributed Papers

I1. Electron Spin Resonance in Frozen Metal-Ammonia Solutions. G. FEHER AND R. A. LEVY, *University of California, Berkeley.*—Electron spin resonance has been observed in frozen ammonia solutions of lithium, sodium, potassium, and cesium. In all samples investigated the signals appear to be the result of metallic particles[1] precipitated out of solution during freezing. Temperature dependences of the width, amplitude, and shape of the signals have been studied from 4°K to 180°K, the melting point of the mixtures. Measurements were carried out in a coaxial transmission cavity at 300 megacycles on samples sealed in Pyrex. In frozen sodium-ammonia the line width varies from 0.15 oersted at 4°K to 6 oersteds at 180°K. In frozen lithium-ammonia the line width is temperature independent except for a transition at 77°K. Below 77° the width is 1.5 oersteds; above 77° the width is 4 oersteds. Frozen potassium-ammonia has a line varying from 5 oersteds at 4°K to 20 oersteds at 170°K. Frozen cesium-ammonia has a 13 oersted line below 30°K which disappears at higher temperatures. Its g value of 1.93 ± 0.02 compares favorably with Brooks[2] calculations of 1.94 for metallic cesium. In none of the solutions studied is line width dependent on concentration of metal solute.

[1] G. Feher and A. F. Kip (to be published).
[2] H. Brooks (unpublished results).

I2. Electron Spin Resonance in Liquid Alkali Metals. R. A. LEVY, *University of California, Berkeley.*—Electron spin resonance in a bulk sample of 99.9 percent sodium has been studied at 300 megacycles between 20°C and 140°C. The line width between maximum slopes follows a linear temperature dependence up to the melting point, 97°C, then increases abruptly by 25 percent in less than 5°. From the melting point to 140°C the width remains unchanged at about 16.5 oersteds. The amplitude of the absorption signal did not change on going through the melting point. The results are compatible with the Elliott[1] mechanism for spin lattice relaxation in metals, giving a linear dependence of the inverse relaxation time on resistivity. The resistivity of sodium jumps 35 percent at the melting point.

[1] R. J. Elliott, Phys. Rev. **96**, 266 (1954).

I3. Electron Spin Resonance in Irradiated Alkali Halides.* A. M. PORTIS AND D. SHALTIEL, *University of Pittsburgh.*—Electron spin resonance has been observed in samples of LiF and LiCl irradiated for a period of 36 hours with 220 kev x-rays. Both samples show inhomogeneous saturation of the resonance similar to that already reported for F centers in KCl, KBr, and NaCl. The g factors for both lines are within experimental error of the free electron g. Both resonances show a surprising response to the magnetic field modulation in that the signal lags the modulating field by nearly 90°. This effect can be understood in a direct way on the basis of hyperfine broadening of lines which are narrow compared with the modulation frequency. We find no resonance in the crystals before irradiation or after the F band has been bleached. The intensity of the resonance is in general agreement with the strength of the F band. We conclude from this evidence and the similarity with the F center resonances in other alkali halides that we are observing genuine F center resonances. We find no evidence for either the resolved spectrum of 19 lines or the broad peak with a gram of 2.018 reported by Schneider.[1]

* This work was supported in part by the Office of Scientific Research of the Air Research and Development Command.
[1] E. E. Schneider, Phys. Rev. **93**, 919 (1954).

I4. Nuclear Magnetic Resonance Spectra of Annular Samples. C. A. REILLY, H. M. MCCONNELL, AND R. G. MEISENHEIMER, *Shell Development Company.*—We have made studies of the nuclear magnetic resonance (NMR) spectra of annular liquid samples. These samples were contained in an annulus between two concentric cylindrical glass tubes, the axes of which are perpendicular to both the static (H_0) and radiofrequency fields in a high resolution NMR spectrometer.[1] The NMR signals from these samples have the appearance of broadened U-shaped doublets, with separations, ΔH, commonly in the range one to five hundred milligauss. Both theory and experiment indicate that

$$\Delta H=4\pi H_0[(\kappa_1-\kappa_2)(a/r)^2+(\kappa_2-\kappa_3)(b/r)^2], \qquad (1)$$

where a, b are the internal and external radii of the inner glass tube, r is the mean radius of the annulus, κ_1, κ_2, and κ_3

are the volume magnetic susceptibilities of (1) material contained in the inner glass tube, (2) glass, and (3) the annular liquid. These observations form the basis of a new, rapid method for the determination of the magnetic susceptibilities of both liquids and solids.

[1] Varian Associates, Palo Alto, California.

I5. Isotope Abundance Ratios by Nuclear Magnetic Resonance. B. E. HOLDER AND M. P. KLEIN, *University of California.*—The Bloch equations for a pair of resonance absorption signals from two isotopes readily lead to an expression for the abundance ratio in terms of the rf amplitude, H_1, the relaxation times, T_1 and T_2, and certain nuclear constants for each of the nuclei. The best signal to noise conditions are realized when the signals are obtained at saturation values of H_1 for the two isotopes. The use of low frequency square wave modulation with the nuclear induction apparatus yields the absorption mode directly. This is in contrast to the sine wave modulation technique which produces the derivative of the absorption curve in a phase sensitive recording instrument. The necessary condition of slow passage is satisfied if the field is swept slowly and the dwell time of the square wave is long compared to the relaxation time. Some experimental data on determination of the natural (H^2/H^1) and (Li^6/Li^7) ratios in paramagnetically relaxed solutions will be presented. This work was performed under the auspices of the U. S. Atomic Energy Commission.

I6. Magnetic Susceptibility Measurements by Nuclear Magnetic Resonance. M. P. KLEIN AND B. E. HOLDER, *University of California.*—Feher and Knight have developed a method for measuring total electronic susceptibilities by nuclear magnetic resonance. The technique makes use of the property that the internal field of a sample subjected to an external field depends explicitly upon the shape and specific susceptibility of the sample. By choosing a sample geometry for which the demagnetizing factors can be theoretically derived, a measurement of the ratio of external to internal field will then determine the specific susceptibility of the sample. The nuclear magnetic resonance of a nuclide contained in the sample provides a direct measurement of the internal field, and the nuclear resonance of the same nuclide in a sample for which the demagnetizing factor is zero, measures the applied field. In practice we employ a sample divided into two sections. For one section the demagnetizing factor is zero, and for the second section the factor is 4π. The nuclear resonance then appears as two lines, the separation being proportional to the susceptibility, $\Delta H/H = 4\pi K$. Thus far only solutions have been studied as the resolution obtainable in solution is higher than for solids. The sensitivity of the method is limited by the homogeneity of the magnetic field and the natural width of the nuclear resonance. This work was done under the auspices of the U. S. Atomic Energy Commission.

I7. Nuclear Magnetic Relaxation in Natural and Synthetic Rubbers.* E. M. BANAS, B. A. MROWCA, AND E. GUTH, *University of Notre Dame.*—Proton magnetic resonance has been observed in unvulcanized natural rubber, Butyl rubber, and Paracril 35 (a 65 parts butadiene, 35 parts acrylonitrile copolymer) from liquid nitrogen to room temperatures. The absorption curves show two more or less abrupt changes of line width with temperature. For unvulcanized natural rubber the first rather sharp drop in line width with increasing temperature occurs at about 125°K. It is at this temperature that Powles and Gutowsky[1] found absorption line narrowing in some tetrasubstituted methanes. This narrowing was attributed to an increased rate of rotation of CH_3 groups about the C_3 symmetry axis. Consequently, this first change could be associated with the onset of CH_3 group rotation in the first two polymers. For unvulcanized Butyl rubber the first sharp drop in line width with increasing temperature occurred in the same temperature region and the line width drops rapidly to about half of its value before leveling off in the vicinity of 150°K. This behavior is consistent with a line narrowing due to rotation in a plane. For Paracril 35 the first rapid decrease in line width with increasing temperature occurs at about 140°K. A second less abrupt change in line width with increasing temperatures occurs in the vicinity of the second-order transition temperature of the polymers.

* Supported in part by the Office of Naval Research.

I8. The Nuclear Magnetic Moments of Rh^{103} and W^{183}. P. B. SOGO AND C. D. JEFFRIES, *University of California, Berkeley.*—The nuclear magnetic moments of Rh^{103} and W^{183} are measured by nuclear induction and found to be: $\mu(Rh^{103}) = -0.08790 \pm 0.00007$ nm and $\mu(W^{183}) = 0.115 \pm 0.001$ nm. The samples consist of metal powders, and the metal shift of the resonance frequencies are calculated to be $(\Delta H_0/H)(Rh^{103}) = (0.25 \pm 0.06)$ percent and $(\Delta H_0/H)(W^{183}) = (2.0 \pm 1)$ percent. Since we have not yet observed the resonances in other than metal samples, these calculated corrections are included in the values quoted above. The ratios of the nuclear magnetic resonance frequencies in the metals to that of D in D_2O containing 1 molar $MnCl_2$ are found to be $\nu(Rh^{103})/\nu(D) = 0.205574 \pm 0.000007$ and $\nu(W^{183})/\nu(D) = 0.27395 \pm 0.00003$. The assistance of The Research Corporation and the U. S. Atomic Energy Commission is gratefully acknowledged.

I9. Direct Measurement of the Nuclear Spin-Lattice Relaxation Time.* J. L. WALSH, A. G. BERGER, J. V. ROGERS, AND W. D. KNIGHT, *University of California, Berkeley.*—A new method for measuring the nuclear spin-lattice relaxation time T_1 is proposed. Oscillating magnetic fields H_1 and H_2 are applied to the sample in directions mutually perpendicular to each other and to a large static field H_0. The frequencies of H_1 and H_2, which are ν_1 and ν_2 respectively, are Larmor frequencies for nuclei in static fields H_0 and $H_0 + \delta H$, respectively, δH being the amplitude of a square wave modulation on H_0. Thus the Larmor frequency is changed from ν_1 to ν_2 and back again in a time equal to the period of the square wave. The field H_1 is supplied by a Pound-Knight oscillator at a level considerably below saturation. H_2 is sufficiently large to cause saturation in a time short compared to the period of the square wave. The electronically integrated curve of power absorption at ν_1 *versus* time is plotted as a function of the period of the square wave. From this curve T_1 can be determined on the assumption that the absorption at frequency ν_1 will rise exponentially with time from the instant δH is removed. The useful limits on this method are for T_1 values from 0.01 to 10 seconds, which is characteristic of many pure metals at temperatures between 1°K and 100°K.

* Supported in part by the Office of Naval Research.

I10. A Diffusion Model for Nuclear Precession Relaxation in Solids. E. L. HAHN AND B. HERZOG, *Watson Scientific Computing Laboratory (IBM).*—A spin dipole field diffusion model is applied to account for the relaxation behavior of free nuclear precession signals from solids where thermal relaxation can be neglected. A configuration of unlike nuclear neighbors B about nucleus A (the precession of A is observed) produces a fluctuating local field at A because of spin-spin coupling among B. We study the case where coupling among A is negligible. The probability that a local magnetic field h_0 at A, due to B, diffuses to another value h_1 in time t is taken from the Ehrenfest model for diffusion of a bound particle between reflecting barriers. The barriers here are represented by $\pm I_B$, where I_B is the total spin of a given B configuration, and the particle unit step is in terms of the local field change at A due to one spin flip in B. The theory predicts the observed dependence of free precession signals on the static field im-

posed by B upon A, and upon spin-spin coupling among B. The experimentally observed effects on A (chlorine) in $NaClO_3$ and para-dichlorobenzene upon decoupling of B by an external magnetic field and upon spin resonance of B are discussed.

I11. Paramagnetic Resonance Absorption in Glass.* R. H. SANDS,† *Washington University.*—A microwave spectrometer operating at 9000 Mc/sec was employed to observe paramagnetic resonance absorption in numerous glass samples furnished by the Corning Glass Works, Corning, New York. Anisotropic spectroscopic splitting factors g of 4.2 and 6.0 were recorded for lines in all glass samples studied. These lines were attributed to an as yet undetermined paramagnetic impurity. The anisotropic g factors must arise from the fine structure produced in the spin states by spin-orbit and Stark interactions. Other lines were recorded near a g of 2, among which were those from Cu^{2+} in network-modifying positions in a soda-lime-silica glass. The resolvable hyperfine structure for these Cu^{2+} ions is evidence for a high degree of short-range order. The fine and hyperfine structure parameters checked well with previous values quoted for the Tutton salts.[1]

* Supported in part by the U. S. Office of Scientific Research, Air Research and Development Command.
† Present address: Stanford University.
[1] A. Abragam and M. H. L. Pryce, Proc. Roy. Soc. (London) **206A**, 164 (1951).

I12. Hyperfine Structure in the Paramagnetic Resonance of Vanadium Ions in Solution.* G. E. PAKE AND R. H. SANDS, *Washington University.*—Paramagnetic resonances of vanadium ions in aqueous, acetone, and ether solutions have been observed. Although attempts were made at preparing valence states V^{3+}, V^{4+}, and V^{5+} in accordance with the procedures of Freed,[1] solutions corresponding in color to V^{3+} and to V^{4+} both gave the same hyperfine pattern of eight $(2I+1)$ lines of different individual widths. The hyperfine coupling constant corresponds to about 120 oersteds, with line spacings being progressively larger toward higher fields as expected in second order[2] for a spectrum centered at 3200 oersteds. The coupling is slightly larger for aqueous than ether solutions, which is not unlikely for solvents forming different complexes with the vanadium ions if the electron promotion hypothesis of Abragam and Pryce[3] for the unexpectedly large hyperfine couplings in such ions is valid. Asymmetric component line shapes for certain solvents and temperatures are interpreted as viscosity effects leading to incomplete averaging of an anisotropic spectroscopic splitting factor of the complexed ion.

* Supported in part by the U. S. Office of Scientific Research, Air Research and Development Command.
[1] S. Freed, J. Am. Chem. Soc. **49II**, 3456 (1927).
[2] B. Bleaney, Phil. Mag. **42**, 441 (1951).
[3] A. Abragam and M. H. L. Pryce, Proc. Roy. Soc. (London) **206A**, 164 (1951).

WEDNESDAY MORNING AT 9:00

310 Le Conte Hall

(E. LOFGREN, presiding)

High-Energy Physics

Invited Papers

J1. European Accelerators. J. R. RICHARDSON, *University of California, Los Angeles.* (30 min.)
J2. Brookhaven 25-Bev Synchrotron. G. K. GREEN, *Brookhaven National Laboratory.* (30 min.)
J3. University of California Bevatron. BRUCE CORK, *University of California, Berkeley.* (30 min.)
J4. Progress with the Stanford Linear Accelerator. W. K. H. PANOFSKY, *Stanford University.* (30 min.)
J5. Design for a Strong-Focusing Electron Synchrotron. M. S. LIVINGSTON, *M.I.T.* (30 min.)

WEDNESDAY AFTERNOON AT 2:30

310 Le Conte Hall

(E. SEGRÈ, presiding)

Invited Papers

K1. Experiments with High-Energy Proton Beams. LEONA MARSHALL, *University of Chicago.* (30 min.)
K2. Polarization Effects on High-Energy Proton-Proton Reactions. R. B. SUTTON, *Carnegie Institute of Technology.* (30 min.)
K3. High-Energy Proton Polarization Studies Involving Triple Scattering. OWEN CHAMBERLAIN, *University of California.* (30 min.)

Contributed Papers

K4. Experimental Determination of the Complete Scattering Matrix in a Proton Carbon Collision. R. TRIPP, C. WIEGAND, T. YPSILANTIS, O. CHAMBERLAIN, AND E. SEGRÈ, *University of California, Berkeley.*—The elastic scattering process of a proton on a particle of spin zero (carbon) is not completely described by the cross section only, but requires the knowledge

of 3 independent parameters which can conveniently be represented by a scattering matrix $g(\theta)+h(\theta)\sigma\cdot n$ where g and h are complex functions of the angle of scattering, σ is the Pauli operator and n is a unit vector perpendicular to the plane of scattering. Besides the amplitudes of g and h only their relative phase has a physical meaning, and for simplicity it is convenient to consider the phase difference β between $g+h$ and $g-h$. A measurement of the scattering cross section and of the polarization gives only two relations and are insufficient to determine the scattering matrix. In order to obtain a third relation we have performed a triple scattering experiment in which the first and second scattering occur in planes perpendicular to each other. After the second scattering the beam is analyzed by a third scattering in a plane perpendicular to the plane of the second scattering and inclined by the same angle θ with respect to the plane of the first scattering. It can be shown that this measurement defines the quantity $\cos(\theta-\beta)$ and hence two possible values of β. This work was done under the auspices of the U. S. Atomic Energy Commission.

K5. Depolarization in Scattering of Polarized Protons by Hydrogen at 310 Mev. T. Ypsilantis, C. Wiegand, R. Tripp, E. Segrè, and O. Chamberlain, *University of California, Berkeley.*—The experiment consists in determining how scattering by hydrogen changes the polarization state of a polarized proton beam. The experiment involves three successive scattering processes. The first scattering on beryllium serves to polarize the protons, the second scattering is on (unpolarized) hydrogen, and the asymmetry at the third scattering (carbon) target serves to analyze the polarization of protons leaving the second target. Wolfenstein has shown that there are two significant new quantities determinable in straight-forward triple-scattering experiments. One of these, D, is a measure of the depolarization in the (proton-proton) scattering, and can be studied directly if all three scattering planes are parallel. D is connected to the observed quantities by the relation $e=(DP_1+P_2)P_3/(1+P_1P_2)$ in which P_1, P_2, and P_3 are the respective polarizations that would be induced in an unpolarized beam by the scattering processes at the first, second, or third target, and e is the observed asymmetry at the third scattering. The other new quantity, R, is a measure of the rotation of the spin produced by the second scattering. This rotation is about an axis perpendicular to the plane of scattering and R can be directly measured in a process in which the second scattering plane is perpendicular to the first scattering plane, and the third plane is perpendicular to the second. This work was performed under the auspices of the U. S. Atomic Energy Commission.

K6. Analysis of Triple Scattering and Correlation Experiments. Henry P. Stapp, *University of California, Berkeley.*—Current triple-scattering experiments measure components of the expectation value of the spin of one of the particles emerging from a $p-p$ collision in which the incident beam is polarized. Another experiment measures simultaneously the spin directions of the two protons which emerge from a collision when the incident beam is unpolarized. These experiments give four new parameters which are characteristics of the $p-p$ system. These, together with the differential cross section and the polarization induced in a single scattering, are expressed in terms of the scattering matrix elements. At $\theta=90°$ there are only three different non-vanishing matrix elements and one may solve for them. There are four possible solutions, and in addition an overall phase factor remains undetermined. The expression for the matrix elements in terms of the $L=0, 1, 2, 3$, $J=0, 1, 2, 3$ phase shifts is obtained. The phase shift analysis will be continued as the experimental results are obtained, and the results reported at the meeting. This work was performed under the auspices of the U. S. Atomic Energy Commission.

K7. Polarization and Cross Section for Inelastic Scattering. M. A. Ruderman, *University of California, Berkeley.*—The differential cross section for the inelastic scattering of high-energy nucleons by nuclei has been studied for energy losses ΔE less than 150 $A^{-\frac{1}{3}}$ Mev. To the extent that a nuclear excitation can be considered as either a collective transition or a change of the nuclear configuration, the cross section for exciting either kind of excited state has been compared to that for elastic scattering. For the prescribed range of ΔE and $2pR\sin\theta/2\lesssim 5$, the ratio of the cross section for exciting a collective transition to that for changing the configuration is greater than $0.2\beta^2A^{\frac{5}{3}}$ where β is the deformation parameter[1] of A. Bohr. If a complex potential is used to describe the effective potential within nuclear matter, then in Born approximation the polarization is independent of ΔE, the same as for elastic scattering, as long as only collective transitions are important. The possibility that the 4.4-Mev level of C^{12} can be considered as a collective excitation and the implications for angular distribution, electron scattering, and polarization will be discussed.

[1] A. Bohr, Dansk. Mat. Fys. Medd. **26**, No. 14.

Wednesday Afternoon at 2:30

4 Le Conte Hall

(W. K. H. Panofsky, presiding)

Contributed Papers

L1. Heavy Meson and Hyperon Production at the Bevatron. Gerson Goldhaber, W. W. Chupp, S. J. Goldsack, J. Lannutti, and F. Webb, *University of California, Berkeley.*—Stacks of nuclear emulsions have been exposed at 90° to the proton beam of the Bevatron (nominal energy 4.8 Bev). The stacks were placed in a re-entrant well at a distance of 10 in. from a plunging target. The only intervening material was the 0.1-in. aluminum wall of the re-entrant well. The stacks are being area-scanned for secondary particles from the target in a region corresponding to a range of 5–6 cm of emulsion. To date, the secondary particles ending or interacting that have been observed are: protons ~700; $\pi+$ 150, $\pi-$ (and μ^- directly from target) 80, μ^+ (directly from target) 5, stars in flight 100, K particles 3. One of the K particles undergoes a scattering in flight of 79°, which is probably a Coulomb scattering from a light element. In emulsion stacks exposed in the direct 3.2 Bev beam (see previous abstract) two events of particular interest were observed among the 2000 proton stars examined. Event A: the interaction of what is possibly a negative hyperon.[1,2] Event B: the emission and interaction of what is probably a 600-Mev α particle. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] M. W. Friedlander, Phil. Mag. **45**, 418 (1954).
[2] Johnston and O'Ceallaigh, Phil. Mag. **45**, 424 (1954).

L2. Ionization Loss in Nuclear Emulsions.* JOHN R. FLEMING AND J. J. LORD, *University of Washington.*—Grain density measurements in 400-micron-thick Ilford *G*-5 plates of accelerated particle tracks have been extended.[1,2] Four separate groups of plates were exposed to a beam of 490-Mev pions. Next, the first group was rotated through 90° and exposed to the 1420-Mev pion beam, and then the second, third, and fourth groups respectively to pions of 1100, 800, and 295 Mev. Preliminary normalized blob densities of pions of 295, 490, 1100, and 1420 Mev were found to be 20.3±0.4, 20.0±0.4, 20.5±0.4, and 21.0±0.4 per 100 microns. The effect of the severity of development on the blob density was investigated by developing one plate in the normal manner and another plate without the application of a warm stage. It was found that the ratio between the blob densities of the 490- and 1100-Mev pions on each plate was within 1 percent of being the same even though the degree of development was quite different. The above measurements of grain or blob density are in good agreement with the theoretical calculations of Sternheimer.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] We are indebted to Dr. R. K. Adair for plates from the cosmotron.
[2] Fleming and Lord, Phys. Rev. **92**, 511 (1953).

L3. π^- Counting by Delayed Coincidence.* K. M. CROWE, R. M. FRIEDMAN, AND H. MOTZ, *Stanford University.*—The counting of π^+ mesons by observing positrons occurring in delayed coincidence with a short-duration primary beam was shown by Alvarez *et al.*, to be a low-background detection scheme of high efficiency. With the Stanford Mark III electron linear accelerator operating at 300 Mev, the beam intensities are sufficient to allow adding magnetic deflection to define the momentum (and charge) of the pions without sacrificing data-gathering rates. With the magnet set for negative particles, we obtain delayed coincidences from some of the π^- mesons which have decayed in flight to μ^-'s. The μ^-'s come to rest in our plastic scintillator (7-in. dia.×10-in. long), and subsequently decay into electrons with essentially the same decay period as the μ^+. The efficiency is high for these events as evidenced by a negative-to-positive yield ratio of ~0.11 on carbon whose π^-/π^+ ratio is approximately one. The following checks have verified the basic scheme. "Negatives" disappear with no magnetic field. They show the correct range-absorption curves for negative μ's; these are somewhat wider than those obtained for positive mesons due to the wider momentum band of the μ's caused by the decay in flight kinematics. The negatives do not show up from bombardment of liquid hydrogen at this energy. The ratio of negatives to positives seems to be insensitive to pion energy.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

L4. π^-/π^+ Ratios in Asymmetric Nuclei.* H. MOTZ, K. M. CROWE, AND R. M. FRIEDMAN, *High-Energy Physics Laboratory, Stanford.*—Using the technique of the preceding abstract, we have measured variations of the negative-positive photopion production ratio for several elements. Large variations have been observed by Littauer and Walker at Cornell University[1] at a laboratory angle of 135°. Our preliminary results at ~300 Mev primary energy at a laboratory angle of 75° are in striking agreement:

	Li	Be	C	S	Ca
L. and W.	2.06±0.18	2.25±0.11	1.06±0.02	0.85±0.03	0.58±0.06
M., C., F.	2.42±0.10	2.61±0.07	1.06±0.02	0.94±0.04	0.70±0.03

In the table we have normalized our carbon ratio to theirs. The probable errors shown are due to counting statistics only. These results are not consistent with more recent work at Cornell (Luckey)[2] and Berkeley (Carrothers),[3] which show less variation with Z. The pion energy, 53±10 Mev, and the electron-beam energy, 300±15 Mev, are measured with a floating-wire technique. We are continuing at different pion energies and with different primary-electron energies. These results will be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. M. Littauer and D. Walker, Phys. Rev. **86**, 838 (1952).
[2] D. Luckey, Phys. Rev. **90**, 711 (1953).
[3] J. Carrothers, Ph.D. dissertation, University of California, Berkeley, 1952 (unpublished).

L5. Mu Meson Ionization in Argon at Energies 10 to 100 Bev.* ALLAN N. WILSON, *University of California, Berkeley.*—The most probable ionization of cosmic-ray mu mesons has been measured by proportional counters containing argon at 4/3 atmospheres. Energy was measured by magnetic field deflection, the incoming and outgoing directions of the particle being defined by small diameter Geiger counters. Particle deflection occurred *in iron* at 18 500 gauss and over a region of 3.5 feet. Multiple scattering did not seriously limit accuracy of energy measurement. The upper limit of resolution of the system was around 200 Bev. Charged particle identification as mu mesons was inferred by justifying absence of electrons, protons, and pi mesons. By range-interval determination of energy, a relative calibration of the counters was performed on minimum ionizing mesons. The results are in good agreement with the density effect calculations of Sternheimer. The onset of this effect occurs at about 10 Bev for argon at this pressure. The highest point plotted, namely at 85 Bev, represents a weighted mean for all cosmic ray mu mesons above 50 Bev; at this point, Sternheimer's theory gives a value of ionization about 1.59 times minimum, as contrasted with 1.70 by the Bethe-Bloch theory. The experiment also yielded a differential mu meson spectrum at sea level, which agrees well with the generally accepted Rossi curve, but which extends beyond that curve in the region 30 to 100 Bev.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

L6. Charged Pion Production in Neutron-Proton Collisions.* GAURANG B. YODH, *University of Chicago.*†—The differential cross section and energy spectra for the production of $\pi^\pm$ mesons by the 400-Mev neutron beam of the Chicago synchocyclotron on liquid hydrogen has been measured at laboratory angles of 90° and 65°, using photographic emulsions as detectors. At 65° (corresponds to 90° in center of mass) roughly equal numbers of positive and negative pions were observed, while at 90° the ratio $\pi^+/\pi^-=2.01\pm0.24$. The experimental cross sections have been reduced to center-of-mass cross sections at a single neutron energy. The differential cross sections at 409-Mev neutron energy are calculated to be:

$$d\sigma^{\pi\pm}/d\omega=(1.07\pm0.39)\mp(1.38\pm0.78)\cos\theta + (0.57\pm1.14)\cos^2\theta\times10^{-26}\ \text{cm}^2/\text{sterad}$$

and the total cross sections are determined to be

$$\sigma(\pi^+)=\sigma(\pi^-)=0.16\pm0.04\ \text{millibarn}.$$

* Research supported by a joint program of U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Stanford University.

L7. π^+ Photomeson Production at 180°. Experimental Arrangement. GORDON W. REPP, MARK J. JAKOBSON, AND R. STEPHEN WHITE, *University of California, Berkeley.*—Hydrogen, deuterium, helium, and carbon were bombarded by photons from the Berkeley synchrotron. π^+ mesons were observed at 180° to the beam. The high-pressure low-temperature gas target[1] was used for hydrogen, deuterium, and helium. Additional data on hydrogen and carbon was obtained from polyethylene and carbon. The mesons were deflected out of the photon beam by means of a magnet. The detector consisted of 2 stilbene crystals on light pipes which were viewed by 1*P*21 photomultipliers. A π^+ meson was identified by means of the coincidence between the π^+ meson and the positron from the

μ^+ meson decay.[2] Absolute cross sections were determined with emulsions exposed to π^+ mesons from hydrogen. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] White, Jakobson, and Schulz, Phys. Rev. **88**, 836 (1952).
[2] J. Steinberger and A. S. Bishop, Phys. Rev. **86**, 180 (1952).

L8. π^+ Photomeson Production at 180°. Experimental Results. R. STEPHEN WHITE, MARK J. JAKOBSON, AND GORDON W. REPP, *University of California, Berkeley.*—The previous paper gave the details of the experimental procedure. In this paper ratios of the cross sections of deuterium, helium, and carbon to hydrogen will be given for π^+ mesons produced at 180° to the beam. The results will be compared to the phenomenological theory of Chew and Lewis and others.[1] Beam monitoring will be discussed and absolute cross sections will be given. These values will be compared with theoretical predictions.[2] The results will be compared to those of other laboratories. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] For a list of references see, e.g., ref. 1 of the above paper.
[2] See, e.g., Brueckner and Watson, Phys. Rev. **86**, 923 (1952); B. T. Feld, Phys. Rev. **89**, 330 (1953); G. F. Chew (to be published).

L9. Scattering and Absorption of 50-Mev π^+ Mesons in Lead. G. SAPHIR, *University of California, Berkeley.*—The interaction of 50 ± 15-Mev π^+ mesons in a $\frac{1}{8}$-inch-thick lead plate have been studied, using a 22-inch cloud chamber in a magnetic field of 5000 gauss. Preliminary cross sections based on 19 100 traversals are: elastic scatters greater than 40 degrees 344 ± 50 mb, stars and stops 1009 ± 75 mb, charge-exchange scattering 37 ± 26 mb. Seven apparently inelastic scatters were found in the forward direction, but six of these are probably $\pi-\mu$ decays just before or within the lead plate. Angular distributions and final results will be presented. This work was performed under the auspices of the U. S. Atomic Energy Commission.

L10. Positron Spectrum from the Decay of the μ Meson. RYOKICHI SAGANE, WALTER DUDZIAK, AND JAMES VEDDER, *University of California, Berkeley.*—Because of the disagreement over the experimental value of ρ (a constant introduced by Michel[1] into the theory of μ-meson decay), an independent measurement was made of this constant with the aid of a 180° β-ray spectrometer. For this experiment the deflected proton beam pulses of the 184-inch cyclotron were used to create low-energy π^+-mesons in a Be target. These low-energy pions, which were stopped in the target, decayed into muons that also stopped in the target. Thus the pion-production target served as a positron source for positrons from the decay of the muon. The spectrum of this positron source was analyzed with a 180° β-ray spectrometer using a fast quadruple coincidence of signals from four plastic crystals. Two types of measurements were made, wherein (a) the distance between the positron source and spectrometer exit slit was kept constant and the magnetic field was varied, and (b) the magnetic field was kept constant and the distance between the source and exit slit varied. A preliminary analysis of the combined results yields $\rho=0.22\pm0.10$. This is in good agreement with the spiral-orbit spectrometer data. This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] L. Michel, Proc. Phys. Soc. (London) **A63**, 514 (1950).

L11. Photomeson Production from H, D, and C. WALTER DUDZIAK, RYOKICHI SAGANE, AND JAMES VEDDER, *University of California, Berkeley.*—Preliminary counter measurements have been made on charged-pion production from hydrogen, deuterium, and carbon at 90° to a photon beam having a maximum photon energy of 300 Mev. For these experiments a 40-inch spiral-orbit spectrometer was used. Pions whose original production energies varied from 14 Mev to 70 Mev were analyzed by the spiral-orbit principle and detected by fast coincidence of pulses from three or four plastic crystals. When the triple-coincidence technique was used, both positive and negative pions were measured at the same time. For these studies a subtraction technique as well as a high pressure deuterium target was used. Data from these preliminary experiments on relative yields of π^+ and π^- mesons will be presented. This work was performed under the auspices of the U. S. Atomic Energy Commission.

L12. π^0 Photoproduction from Protons and Deuterium Nucleons, I.* R. M. WORLOCK AND W. R. SMYTHE, *California Institute of Technology.*—A thin-walled gas target was irradiated with 500 Mev bremsstrahlung from the California Institute of Technology synchrotron. The proton spectrum emerging from the hydrogen, the deuterium, and the empty target was investigated at three angles: 30°, 41°, and 52°. The protons were identified by measurement of specific ionization in the front counter of a three counter scintillation telescope consisting of two counters in coincidence and the rear counter in anti-coincidence. The proton energy was determined by its range, and photon energy was determined by proton energy and angle since the processes studied were two body reactions. The angular resolution was triangular with 4.8° full width and the proton energy resolution was typically 9 Mev. A method involving runs with a lead plug in the telescope was devised to give an accurate background correction. Following are the proton count ratios from deuterium and hydrogen. At proton lab angle of 30°: Proton energy $=53$ Mev, $D/H=2.23\pm0.17$; 61, 2.04 ± 0.12; 70, 1.56 ± 0.09; 85, 1.51 ± 0.09; 98, 1.56 ± 0.11; 108, 1.71 ± 0.14; 124, 2.05 ± 0.25; 134, 1.93 ± 0.21; 148, 2.35 ± 0.40. At 41°: 48, 1.60 ± 0.13; 57, 1.17 ± 0.08; 70, 1.40 ± 0.11; 79, 1.60 ± 0.11; 88, 1.71 ± 0.18; 100, 1.81 ± 0.26; 108, 1.96 ± 0.32. At 52°: 46, 1.50 ± 0.10; 52, 1.63 ± 0.13; 57, 1.74 ± 0.20; 62, 2.37 ± 0.21; 70, 2.72 ± 0.32.

* This work was supported in part by the U. S. Atomic Energy Commission.

L13. π^0 Photoproduction from Protons and Deuterium Nucleons, II.* W. R. SMYTHE AND R. M. WORLOCK, *California Institute of Technology.*—From the data described in the preceding abstract the absolute cross section and angular distribution coefficients for the reaction $\gamma+P\rightarrow P+\pi^0$ were obtained for photon laboratory energies from 265 to 450 Mev. The results are approximately 20 percent smaller than those obtained by Oakley[1] at this laboratory using a magnetic spectrometer. There is evidence indicating that in the photoproduction of mesons from deuterium the photon interacts only with one of the nucleons, and the subsequent motion of the second nucleon is determined primarily by its motion in the deuteron prior to the photon interaction. Assuming this hypothesis, the photon on deuteron reaction becomes a two body problem except for smearing due to the initial momentum distribution of the interacting nucleon. The reaction $\gamma+D$ can give the following products: $P+\pi^0+(N)$; $D+\pi^0$; $N+\pi^+ +(N)$; $P+\pi^-+(P)$; $P+N$; $P+\pi^0+(N)$. Only the last three reactions contribute protons. By suitable combination it is possible, using the data from this experiment and known cross sections, to obtain the cross section for production of π^0 mesons from the neutron and proton in the deuteron.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] D. C. Oakley, thesis, California Institute of Technology, 1954 (to be published).

L14. A Study of the Reaction $H^1(H^2He^3)\pi^0$ at 340-Mev Proton Energy. K. C. BANDTEL, W. J. FRANK, L. HIGGINS, AND B. J. MOYER, *University of California, Berkeley.*—The ratio of the cross section for the reaction $H^1(H^2H^3)\pi^+$ to the above reaction has been determined to be 2.3 ± 0.3 at one angle in the center of momentum system.* This evidence supports

the hypothesis of charge independence. As a further test, the angular distribution of the $H^1(H^2He^3)\pi^0$ is being measured for several angles by identifying the He^3 particle. A pulse height technique for measuring E and dE/dx is being used. The pulse heights are photographed on the sweep of a Tetstronix 517 scope. The angular distribution and yield of the reaction $H^1(H^2H^3)\pi^+$ has been measured,† and a comparison with the $H^1(H^2He^3)\pi^0$ cross section will give information about the hypothesis of charge independence. This work was performed under the auspices of the U. S. Atomic Energy Commission.

* American Physical Society Washington Meeting, 1954.
† Frank, Bandtel, Madey, and Moyer, Phys. Rev. **94**, 1716 (1954).

WEDNESDAY AFTERNOON AT 2:30

1 Le Conte Hall

(J. KAPLAN, presiding)

Contributed Papers

M1. Second-Neighbor Interaction in a Two-Dimensional Graphite Lattice. G. S. COLLADAY AND S. BARSHAY,[1] *U. S. Naval Ordnance Test Station.*—Using a LCAO wave function for the π electrons of a two-dimensional graphite lattice, the energy as a function of wave number vector $E(\mathbf{K})$ can be obtained under the approximation that (I) only interactions between nearest neighbors are included, or (II) interactions between both first and second nearest neighbors are included.[2] Density of states curves for the valence and conduction bands for (I) and (II) have been numerically computed. The desirability of including the second nearest neighbor interaction is indicated by comparing for (I) and (II) the density of states curves for valence and conduction bands, the effective mass of the π electrons, the effective number of conduction electrons, and the resonance energy of graphite.

[1] Now at the University of California, Berkeley.
[2] G. S. Colladay, Bull. Am. Phys. Soc. **29**, No. 6, 11 (1954), abstract B7.

M2. Magnetic Domains in a Single Crystal of Cobalt near 275°C by the Longitudinal Kerr Effect.* EDWARD M. FRYER AND CHARLES A. FOWLER, JR., *Pomona College.*—Hexagonal cobalt passes through a state of zero anisotropy at a temperature of about 275°C.[1] At this temperature the easy direction of magnetization changes from the hexagonal axis to one of the transverse axes. Photographic observations of magnetic domain patterns, by means of the longitudinal Kerr effect[2,3] as this temperature is approached and exceeded, indicate a shift in the domain structure from the one direction to the other. Photographs suggest a gradual widening of the domain wall as the transition temperature is approached, an apparent absence of domains when the crystal is isotropic, followed by a formation of new domains in a transverse direction as the temperature is further increased. On cooling, domains reappear in the original direction, becoming sharper as the crystal is cooled back to room temperature.

* Supported by the Office of Naval Research.
[1] R. M. Bozorth, *Ferromagnetism* (D. Van Nostrand Company, Inc., New York, 1951), p. 555.
[2] C. A. Fowler and E. M. Fryer, Phys. Rev. **94**, 52 (1954).
[3] C. A. Fowler and E. M. Fryer, Phys. Rev. **95**, 564 (1954).

M3. Temperature Dependence of the Heat Capacity of Molybdenite.* EDGAR F. WESTRUM, JR., AND JOHN J. MCBRIDE, *University of Michigan.*—To test the applicability of the recent treatments of thermal properties of lamellar lattices,[1] we have determined the heat capacity and derived thermodynamic functions for a highly purified molybdenite MoS_2 sample and for boron nitride over the range 5 to 300°K. The temperature dependence of the heat capacity of molybdenite is proportional to T^x if x gradually decreases from about three at 7° to less than two at 60°K. An essentially similar result has been found in this laboratory for crystalline boron nitride in contrast to the data reported by others.[2] However, the "sandwich" (S−Mo−S) lamina of molybdenite show as T^3 a dependence as that claimed by DeSorbo[3] for graphite and by Dworkin, Sasmor, and Van Artsdalen[3] for boron nitride. The significance of the temperature dependence is discussed. The entropy (S^0), and enthalpy increment ($H^0-H_0^0$) of molybdenite are 14.96±0.02 cal deg^{-1} $mole^{-1}$ and 2528.±3 cal $mole^{-1}$, respectively, at 298.16°K.

* Supported in part by U. S. Atomic Energy Commission.
[1] Tarassov, Compt. rend. acad. sci. U.R.S.S. **46**, 20, 110 (1945), and others.
[2] Dworkin, Sasmor, and Van Artsdalen, J. Chem. Phys. **22**, 5, 837 (1954).
[3] DeSorbo and Tyler, J. Chem. Phys. **21**, 1660 (1953).

M4. A Second Transition in $AuCu_3$.* G. C. KUCZYNSKI AND M. DOYAMA, *University of Notre Dame.*—The alloy $AuCu_3$, when heated, undergoes a transition from the ordered to the disordered state at about 391°C. Experiments on the kinetics of ordering carried out in this laboratory have shown a discontinuity in the rates of ordering of this alloy when disordered below and above 600°C, suggesting a possible change of phase. Careful specific heat measurements revealed a definite peak between 560° and 590°C. Measurements of the yield point and electrical resistance also showed discontinuities in that range of temperature. It can therefore be concluded that a second phase transition takes place in $AuCu_3$ in the vicinity of 590°C.

* Supported by Office of Naval Research.

M5. Effect of External Stresses upon the Rate of Ordering of AuCu.* A. R. FREDA AND G. C. KUCZYNSKI, *University of Notre Dame.*—AuCu wires were ordered at various temperatures below the critical temperature, under stresses varying from 0 to 200 kg/cm^2. It has been found that in the temperature range between 350° and 400°C the rate of ordering as measured by electrical resistivity was increased greatly in specimens ordered under external stress. Below 350°C no appreciable difference has been noted. Analysis of the results seems to indicate that the rate of nucleation is affected more than the rate of growth of the ordered domains. The effect increases greatly with increase in applied stress. No observable influence of external stress upon the rates of ordering in $AuCu_3$ has been observed.

* Supported by Union Carbon and Carbide Company.

M6. Rectification in Thin Films of PbS. M. SILVER, R. S. WITTE, AND F. MCCAFFREY, *U. S. Naval Ordnance Test Station.*—An induced rectification effect has been observed in chemically deposited PbS cells[1] and has been studied under various conditions of bias, temperature and atmosphere. A similar effect has been observed in evaporated PbS cells at 250°C.[2] The rate of polarization is voltage and temperature dependent. Experiments indicate that the barrier is in the

vicinity of the negative electrode with a back to forward resistance ratio of up to 10 to 1. It is further observed that the forward resistance decreases with time. To the first order, the polarization is atmosphere independent. Experiments have been performed in air (0 percent and 50 percent relative humidity) at atmospheric pressure and in vacuum at 10^{-4} mm of Hg. Rectification was observed with both gold and Aquadag electrodes. Once polarized, the cells exhibit considerable stability in resistance, sensitivity and noise as long as the polarizing bias is maintained. If the bias is removed the cell reverts to the unpolarized state. The rate of recovery is slow at room temperature but increases rapidly with increasing temperature.

[1] Observed independently by David Dutton, University of Rochester (private communication).
[2] Starkiewicz, Sosnowski, and Simpson, Nature **158**, 28 (1946).

M7. Donor and Acceptor Ionization Energies in Silicon and Germanium.* A. H. MITCHELL AND C. KITTEL, *University of California, Berkeley.*—An exact theory of impurity states in crystals is developed, and an evaluation is given of the applicability of the Wannier equation to the donor states in Si and Ge in view of the multiple energy minima in the conduction band. The theory is extended to include degenerate bands, and it is shown by two different methods that the Wannier equation is to be replaced by a set of coupled wave equations. The theory is applied to acceptor states in Si and Ge. The agreement with experiment is fairly good for both donors and acceptors.

* This work is supported in part by the Office of Naval Research and the U. S. Signal Corps.

M8. Internal Friction as a Function of Cold Work of Copper Reeds at Low Frequencies. J. J. BRADY, M. B. LARSON, AND T. A. O'HALLORAN, *Oregon State College.*—The internal friction of copper reeds was measured by the resonance method of Jewell[1] for frequencies between 54 and 540 cycles per second. The reeds were annealed in a vacuum by passing a current through them. The Q^{-1} was then measured as a function of strain amplitude between 5×10^{-4} and 5×10^{-3}. Successive measurements were made after subjecting the sample to compressive loads ranging from 1800 lb/in.^{2} to 9000 lb/in.^{2}. For a frequency of 85.5 cps the cold-worked sample had a Q^{-1} greater than the annealed sample for strain amplitudes less than 2×10^{-3} but for greater strain amplitudes the Q^{-1} decreased with cold-working. The samples were polycrystalline.

[1] W. R. Jewell, Rev. Sci. Instr. **24**, 5 (1953).

M9. Order-Disorder and Ionic Conductivity in Ag_2HgI_4. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—Ketelaar[1] has shown ordered Ag_2HgI_4 to consist of full Ag planes, half full Hg planes, and full I planes in the order Hg−I−Ag−I, disordered having the metal atoms randomly distributed over four sites with the I lattice unaffected, ionic conductivity due to Ag only. The specific heat anomaly yields a straight line when its logarithm is plotted *vs* $1/T$, of slope corresponding to 10.7 kcal/mole, 2/3 of which applies to Ag. Close to perfect order, the elementary act of disordering must be the jumping of Ag to vacancies in Hg plane, producing a pair of current carriers (Ag ion and vacancy), so that activation energy of (1/2)(2/3)(10.7) kcal should be observed for ionic conductivity over the anomalous range, 3.6 kcal was observed. The pairs are analogous to Frenkel defects or hole-electron pairs and should relax bimolecularly like Cu_2Au.[2] Activation energies for ionic conduction in ordered and disordered phases (respectively structure-sensitive and intrinsic) correspond respectively to one and one-half vacancies available per elementary act of conduction.

[1] J. A. A. Ketelaar, Z. Krist. **80**, 190 (1931) and **87**, 436 (1934), Z. phys. Chem. **26B**, 327 (1934) and **30B**, 53 (1934).
[2] J. Rothstein, Phys. Rev. **94**, 1429(A) (1954).

M10. Brillouin Zone Studies of Alloys. III. Matthiessen's Rule for Dilute Magnesium Alloys. E. I. SALKOVITZ, J. PASTERNAK, AND A. I. SCHINDLER, *Naval Research Laboratory.*—An analysis of H. Jones[1] theory of the Brillouin zone structure of magnesium alloys has led Salkovitz and Schindler[2] to suggest that interesting electrical effects might be observed near solute concentrations where electron overlap occurs. Preliminary data on the Hall coefficient[3] have already borne this out. In reference 2 it was suggested that one might find departures from Matthiessen's rule, which states that the temperature change of resistivity ($d\rho/dT$) in dilute alloys is concentration-independent. Therefore the resistivity of a series of dilute binary alloys of magnesium were measured in the temperature range of 20°–35°C in steps of 0.2°C. The solute atoms were Ag, Cd, In, Sn, Al, Tl, or Pb in various concentrations. It was found that as solute atoms were added, $d\rho/dT$ remained relatively constant up to an electron to atom ratio of about 2.013. At this value there was an abrupt drop of 5 percent in the value of $d\rho/dT$ with additional solute atoms. For still greater additions, $d\rho/dT$ continued to decrease slowly. The temperature coefficient of resistivity ($\alpha=d\rho/\rho dT$) decreased rapidly with alloying up to the electron to atom ratio of about 2.013.

[1] H. Jones, Proc. Roy. Soc. (London) **A147**, 400 (1934).
[2] E. I. Salkovitz and A. I. Schindler, Phys. Rev. **91**, 234 (1953).
[3] A. I. Schindler and E. I. Salkovitz, Phys. Rev. **91**, 1320 (1953).

M11. Linear Magnetostriction of Some Ternary Cobalt-Iron-Nickel Alloys. H. E. STAUSS AND G. SANDOZ, *Naval Research Laboratory.*—Measurements of linear magnetostriction have been made of ternary cobalt-iron-nickel alloys with high cobalt content. In the case of most of the ternary alloys examined, the linear magnetostrictions that were observed at the highest magnetic inductions attained (approximately saturation magnetostrictions) were less than the published values of saturation magnetostriction for binary cobalt-iron alloys with the same cobalt content. In the restricted range of alloys containing 45- to 60-percent cobalt, the substitution of about 5 percent or less of nickel for iron appeared to result in small increases of magnetostriction up to about 10 percent as compared with binary alloys of like cobalt content. No values of magnetostriction were found in the ternary alloys that were greater than the larger published values for the binary cobalt-iron alloys. Data concerning the change of magnetostriction with magnetic induction are given for the alloys.

M12. Thermal Conductivity of Germanium at Ambient Temperatures. KATHRYN A. MCCARTHY AND STANLEY S. BALLARD,* *Tufts College.*—The thermal conductivity of germanium has been measured by a comparative method[1] in which cast zinc[2] of high purity was used as the standard. The germanium samples, prepared and made available by the Westinghouse Research Laboratories, were stated to contain about 10^{14} electrical impurities per cm^3. Values measured for the thermal conductivity of these samples were: at 35°C, 0.57 watt cm^{-1} °C^{-1}; at 5°C, 0.61 watt cm^{-1} °C^{-1}. These results are in substantial agreement with those reported by Grieco and Montgomery.[3]

* Present address: Scripps Institution of Oceanography.
[1] Ballard, McCarthy, and Davis, Rev. Sci. Instr. **21**, 905–907 (1950).
[2] *Zinc and Its Alloys* (National Bureau of Standards, Washington, D. C., 1931), Circular No. 395, pp. 69–71.
[3] A. Grieco and H. C. Montgomery, Phys. Rev. **86**, 570 (1952).

M13. Investigation of a Polymorphic Transition in Iron at 130 k.b.* STANLEY MINSHALL, *Los Alamos Scientific Laboratory.*—Propagation of compressive waves generated by high explosives in Armco iron may, under certain conditions, occur with three stable shocks. The characteristics of these have been investigated by means of the pin technique. Data will be presented to show that the three waves are consistent with the hypothesis of a dynamic elastic limit of 6.7 k.b., and a polymorphic transition of about 130 k.b.

* Work done under the auspices of the U. S. Atomic Energy Commission.

THURSDAY MORNING AT 9:00

310 Le Conte Hall

(R. T. BIRGE, presiding)

Nuclear and Electron Resonance

Invited Papers

N1. Cyclotron Resonance in Solids. A. F. KIP, *University of California, Berkeley.* (30 min.)
N2. Nuclear Resonance and the Study of Metals. C. P. SLICHTER, *University of Illinois.* (30 min.)
N3. Paramagnetism of the Transuranic Elements. C. A. HUTCHISON, JR., *University of Chicago.* (30 min.)
N4. Paramagnetic Resonance of Free Radicals. G. E. PAKE, *Stanford University.* (30 min.)

THURSDAY MORNING AT 9:00

3 Le Conte Hall

(W. E. LAMB, presiding)

Invited Paper

O1. Problems of the Diffraction of Light with Demonstrations by Video. F. ZERNIKE, *Groningen, The Netherlands.* (30 min.)

Contributed Papers

O2. The Magnetic Moment of Free Electrons. D. J. BESDIN AND JOSEPH H. ROBINSON III, *Texas Technological College.*—Many elegant methods have been applied to compute the magnetic moment of a system of free electrons confined in a box. If the electron wave functions are required to vanish at the walls, all states are obtained and no distinction need be made between the various orbits. However, an exact and general statistical determination of the moment of the system has not been possible so far because of computation difficulties with the Fermi-Dirac summation. Results reported so far from computing the free energy appear to be not wholly reliable because of H dependence of the limits of summation and the degeneracy-of-states factor. It appears, therefore, that an exact numerical determination may be useful for checking earlier work and indicating trends. We have verified and extended the results at absolute zero temperature obtained previously by one of us for a cylindrical box with a uniform field along the axis.* Results obtained are reminiscent of the deHaas-van Alphen effect, and it is planned to extend the work to higher temperatures.

* D. J. Besdin, Phys. Rev. **79**, 417 (1950); unpublished thesis, Rice Institute (1950).

O3. Random Walk Methods in Statistical Mechanics of One-Dimensional Systems.* R. L. SELLS, C. W. HARRIS, AND E. GUTH, *University of Notre Dame.*—We have shown that random walk methods yield in the simplest possible way equations of state and (pair) distribution functions of one-dimensional gases with nearest neighbor interaction only. For such systems Bethe's method of treatment of order-disorder phenomena is exact and an appropriate form of the superposition principle is valid rigorously. The corresponding Born-Green (and/or Kirkwood) type of integral equation can be shown to be linear and of the convolution type. This can be seen most simply by repeated application of the operation of convolution to the pair distribution function for adjacent molecules. This pair distribution function in turn is given simply by Boltzmann's principle and is a Poisson distribution modified by the presence of the interaction potential (with hard core) between the molecules. This study is preliminary to an attempted treatment of a one-dimensional gas where all molecules interact with each other. Such a system will plausibly show a phase transition. In fact the corresponding one-dimensional Ising model does show a phase transition. The existence of this transition can be proved, but the explicit construction of the partition function is difficult. This system is about intermediate between the two- and three-dimensional Ising models with nearest neighbor interaction.

* Supported in part by the Office of Naval Research.

O4. Role of Coordination Number in the Lee-Yang Lattice Gas.* C. W. HARRIS, AND E. GUTH, *University of Notre Dame.*—Lee and Yang[1] considered a lattice gas corresponding to Onsager's solution of a square Ising model. We have considered the lattice gases corresponding to hexagonal, triangular, and kagomé Ising models also. In accordance with physical expectation the critical constant $(\eta_c V_c/kT_c)$ increases with the coordination number from 0.0742 for the hexagonal case to 0.0966 for the square case and further to 0.1182 for the triangular case. The last case comes closest to reality. These lattice gases will be compared with a Lennard-Jones and Devonshire type of two-dimensional cell-gas using a square well interaction between pairs of atoms.

* Supported in part by Office of Naval Research.
[1] T. D. Lee and C. N. Yang, Phys. Rev. **87**, 410 (1952).

O5. Effect of the Extended Size of the Nucleus on μ-Meson Pair Photoproduction.* GEORGE RAWITSCHER,† *Stanford University.*—In the case of μ-pair creation by photons, the momentum transfer q to the nucleus is large enough to introduce into the usual point-charge differential Bethe-Heitler cross section a reducing form factor dependent on q and on the shape of the

nucleus. The cross section $d^2\sigma/dEd\Omega$, in which the angle and momentum p of one of the mesons $(-)$ is held fixed, was calculated using the Stanford Card-Programmed-Calculator. The ranges for the parameters $(1.68 \leq p/\mu c \leq 3.72;\ \theta = 10°;$ $4.00 < k/\mu c^2 < 5.70)$ were chosen to correspond to an experiment now in progress at the High-Energy Physics Laboratory. The results for $p/\mu c = 2.73$, folded into the 500-Mev bremsstrahlung spectrum dk/k, and normalized to the corresponding point-charge Bethe-Heitler results are, respectively, 1, 0.318, 0.157, 0.032, 0.028 for $A = 0$, 27, 63, 207, 238. It is felt that for lower energies this form-factor effect will be even more pronounced.

* Partially supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† C. B. P. F., Rio de Janeiro, Brazil, at Stanford under a Fellowship of the Brazilian National Research Council.

O6. Lattice Space Quantization of Coupled Meson and Nucleon Fields.* D. H. HOLLAND, *Stanford University.*—The lattice space quantization method used by Schiff[1] for treating nonlinear mesons is fused in quantizing coupled meson and nucleon fields. Neutral pseudoscalar mesons with pseudoscalar coupling to neutral Dirac nucleons are assumed. Only the fields at the lattice points of a cubic lattice are considered. An appropriate lattice-space Hamiltonian is found and momentum (gradient) terms are treated as perturbations. To zero order the lattice points are uncoupled, so the state function can be written as a product of functions describing a single point. In the representation chosen, finding a particular point function entails the solution of a set of coupled differential equations. These equations can be solved in principle with no assumptions as to the magnitude of the coupling constant g. Linear combinations of the zero-order solutions can be found which diagonalize the perturbation to lowest order and can be interpreted as one-particle momentum eigenstates. Linear combinations of two-particle momentum eigenstates are found which approximately diagonalize the perturbation, and from these scattering cross sections are calculated.

* Supported by the Office of Scientific Research, Air Research and Development Command.
[1] L. I. Schiff, Phys. Rev. **92**, 766 (1953).

O7. Pion-Nucleon s-Wave Phase Shift from $ps-ps$ with Cutoff. CHARLES J. GOEBEL, *University of California, Berkeley.**—An investigation of the pion-nucleon s-wave scattering in the $ps-ps$ theory is made, using a cutoff $\leq$ the nucleon mass, and the ("exact") Foldy nonrelativistic transformation of the Hamiltonian. The calculation of the phase shifts in the 1-meson $T-D$ approximation yields (choosing an appropriate cutoff) a large i-spin dependent term, but this term is spurious since it violates the Gell-Mann and Goldberger[1] "crossing theorem." The spurious term disappears in an (approximate) 3-meson $T-D$ calculation (meson-meson interaction is not included) with the result that no appreciable i-spin dependence is found from this theory.

* Part of a thesis done at the University of Chicago. Supported in part by the U. S. Atomic Energy Commission.
[1] M. Gell-Mann and M. Goldberger (unpublished); but see, e.g., Proc. Fourth Annual Rochester Conference on High Energy Nuclear Physics, p. 29.

O8. A Variational Principle for Tensor Forces. J. L. MCHALE AND R. M. THALER, *Los Alamos Scientific Laboratory.*—In calculating nucleon-nucleon scattering, it proved convenient to formulate the Schwinger variational principle for coupled states[1,2] in terms of quantities $X_{\alpha,\beta}$ and $Y_{\alpha,\beta}$ defined by

$$\varphi_i = \begin{pmatrix} u_J{}^i \\ w_J{}^i \end{pmatrix} \sim \begin{pmatrix} F_{J-1}\delta_{i\alpha} + X_i G_{J-1}\delta_{i\alpha} + Y_i G_{J-1}\delta_{i\beta} \\ F_{J+1}\delta_{i\beta} + X_i G_{J+1}\delta_{i\beta} + Y_i G_{J+1}\delta_{i\alpha} \end{pmatrix}. \quad (1)$$

The α solution corresponds to incident wave in channel $L = J-1$ and, no incident wave in channel $L = J+1$; the β solution corresponds to incident wave in channel $L = J+1$. F_L and G_L are regular and irregular solutions of the homogeneous equation. Time reversal or the Wronskian require $Y_\alpha = Y_\beta$. The stationary expressions for X, Y avoid treating any of them on a special footing, and are similar to Schwinger's expression for eigenphase shifts. Diagonalization of the S matrix requires that the mixture parameter[2]

$$\eta = -(X_\alpha - X_\beta)/2Y \pm [(X_\alpha - X_\beta)^2/4Y^2 + 1]^{\frac{1}{2}}$$

with $\eta_+\eta_- = -1$, and $\tan \delta_\pm = X_\alpha + \eta_\pm Y = X_\beta + (\eta_\pm)^{-1} Y$, where $\delta_\pm$ are eigenphase shifts. Modification of the η condition yields the usual complex phase shifts of the undiagonalized S matrix.

[1] L. C. Biedenharn and J. M. Blatt, Phys. Rev. **93**, 1387 (1954); Phys. Rev. **86**, 399 (1952).
[2] F. Rohrlich and J. Eisenstein, Phys. Rev. **75**, 705 (1949).

O9. Optical Model Analysis of Scattering of 14-Mev Neutrons. I. N. SHERMAN, G. CULLER, AND S. FERNBACH, *University of California, Livermore.*—Calculations of the angular distributions of elastically scattered neutrons and of reaction and total cross sections at 14 Mev have been performed, based on the optical model of the nucleus. The central field was described by a complex potential in the form of a "square well with a tail." The depth and shape of the complex potential were varied in attempts to fit available experimental data. The report will show the best fits for: (a) the experimental angular distributions[1] of C, Al, Cu, Sn, and Pb; (b) the experimental reaction cross sections[2] of B, C, N, Al, Fe, Cu, Cd, Au, and Pb; (c) the experimental total cross sections[3] as a function of atomic number. The complex potentials which yield these fits will be discussed. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Private communication from J. Coon.
[2] Phillips, Davis, and Graves, Phys. Rev. **88**, 600 (1952).
[3] Coon, Graves, and Barschall, Phys. Rev. **88**, 562 (1952).

O10. Optical Model Analysis of Scattering of 14-Mev Neutrons. II. Polarization Effects. S. FERNBACH, G. CULLER, AND N. SHERMAN, *University of California, Livermore.*—The potentials used in the calculations reported in the previous paper have been modified to include a spin-orbit interaction of the form $f(r)\boldsymbol{\sigma}\cdot\mathbf{L}$. A study of variation of polarization and elastic cross section as a function of $f(r)$ and A is under way. Preliminary results indicate that the effect of including the spin-orbit terms is to damp the usual large oscillation in the diffraction pattern, especially at large angles. Experimental angular distributions for scattered protons show the same qualitative features, so that it seems that future proton calculations could profitably include the spin-orbit terms. The absence of minima at the expected angles of the diffraction pattern for scattered 300-Mev nucleons can be explained in the same way. Quantitatively, the results to data show that the maximum percentage polarization of the 14-Mev neutrons varies in a somewhat unpredictable way as a function of A. For $f(r) \approx 2$ Mev over the entire nucleus, a maximum of 95 percent is reached for aluminum, 56 percent for copper, 15 percent for tin, and 63 percent for lead. Keeping $f(r)$ constant over the nucleus but varying its magnitude appreciably affects the maximum percentage polarization as well as the diffraction pattern. In the case of lead, the best value of $f(r)$ was found to be ≈ 0.25 Mev. This work was performed under the auspices of the U. S. Atomic Energy Commission.

O11. On Dirac's Method Using Complex Variables in Quantum Mechanics.* EUGENE GUTH, *University of Notre Dame.*—Dirac[1] introduced essentially the (one-sided) Laplace transform of the radial Schrödinger wave function. This obeys an integral equation similar to that obeyed by momentum transforms. In general, determination of the eigenvalues (and

of the eigenfunctions) needs considerations in the complex plane. It is pointed out, however, that for *S*-states in a Coulomb field the integral equation reduces to a linear differential equation of the first order and the eigenvalues follow from the postulate of the uniqueness of the wave function. The simple operator calculus involved in the transition from the Hamiltonian to the wave equation for the Laplace transform of the coordinate wave function resembles Heaviside's calculus. To the first power of the radius vector there corresponds differentiation according to the parameter of the Laplace transform, while to the reciprocal of the radius vector there corresponds integration according to the same parameter.

* Supported in part by the Office of Naval Research.
[1] P. A. M. Dirac, Proc. Roy. Soc. (London) **A160**, 48 (1937). Essentially the same method was later developed independently in great detail by H. Kallmann and M. Päsler; cf, e.g., Ann. Physik (6) **2**, 92 (1948).

O12. On the Theory of Successive Orientational Phase Transitions in Two- and Three-Dimensional Systems.* T. E. Lockary and E. Guth, *University of Notre Dame.*—Krieger and James[1] considered a system of three-dimensional rotators fixed in space. For an interaction energy between nearest neighbor rotators which depends only on the angle between their axes and consists of the sum of the first two spherical harmonics, single first- and second-order transitions and even two successive first-order transitions were obtained depending upon the ratio of the coefficients of the spherical harmonics. In the present work a simplified method was developed which was shown to yield all of Krieger and James' principal results. This method was then applied to a two-dimensional system of rotators, the spherical harmonics being replaced by the corresponding cosines. Application of the internal field approximation shows a single second-order transition, a single first-order transition, a first-order transition followed by a second-order transition as the temperature increases, or two second-order transitions depending on the value ratio of the coefficients. The less complete results of the method of Bethe and Chang verify these results qualitatively while changing numerical values slightly in the range accessible to this treatment. Use of more complicated interactions in the internal field approximation indicate the possibility of several successive transitions in the system.

* Supported in part by the Office of Naval Research.
[1] T. J. Krieger and H. M. James, J. Chem. Phys. **22**, 796 (1954).

O13. Two-Dimensional Coulomb Scattering in Quantum Mechanics.* Ming Chen Wang and Eugene Guth, *University of Notre Dame.*—For three-dimensional Coulomb scattering, classical theory, Born approximation, and exact quantum-mechanical theory all lead to the same (Rutherford's) result. For two-dimensional Coulomb scattering (retaining the inverse square law, instead of the logarithmic potential), the exact result contains Planck's constant and gives different results for the Born and the classical limits. This result is of methodological interest.

* Supported in part by the Office of Naval Research.

O14. A Formulation of Probability Theory as a Physical Theory.—A. O. Barut,* *University of Chicago.*—The theory of probability when applied to quantum mechanics appears to be modified and restricted and there is an inconsistency in the use of probability rules. These facts are due to the incompletness of the probability theory itself in describing the physical world. Probability statements must include the experiment, all possible outcomes of it, as well as the system on which the experiment is carried on. The experiment is taken to be the primary concept. One way of formulating such a completed probability theory is to represent the random variable (experiment) by an Hermitian operator in a Hilbert space, for then the postulates of the inner product in Hilbert space are of the same structure as the postulates of the probability theory. Furthermore the rules for the addition and multiplication of probabilities have no logical connections with the postulates. Such rules must be in agreement with the experiments and it is possible to formulate them in such a way as to contain the superposition principle of physics. The postulates of the quantum theory can then be reduced to a single principle: that "observables are random variables."

* Now at Reed College.

Thursday Morning at 9:00

4 Le Conte Hall

(L. W. Alvarez, presiding)

Contributed Papers

P1. Disintegration of Oxygen by 300-Mev Neutrons. Melvin Otis Fuller, *University of California, Berkeley.*—The 300-Mev neutron beam of the Berkeley cyclotron was used to produce disintegrations of oxygen nuclei in an oxygen-filled cloud chamber situated in a 21 700 gauss pulsed magnetic field. Pictures of the "stars" thus formed were reprojected and measured, permitting identification of most of the ejected particles and computation of their energies and momenta. Each star consisted of one or more tracks due to heavy particles of one or two charges, plus the track of the recoil nucleus. The random selection of 602 stars shows approximate percentages according to total prongs as follows: 2-prong, 42 percent; 3-prong, 29 percent; 4-prong, 12 percent; 5-prong, 12 percent; 6-prong, 4 percent; 7-prong, 1 percent; plus one 8-prong star. Energy measurements of the prongs showed 29 percent as having over 15 Mev, 16 percent over 50 Mev, and 8 percent over 100 Mev. Using 15 Mev as a division point for slow and fast particles, the slow particles were 37 percent alphas, 33 percent protons, and 22 percent deuterons, and the fast particles 66 percent protons, 20 percent deuterons, and 9 percent alphas. The energy spectra of the slow particles show maxima at about 2, 3, and 4 Mev for the protons, deuterons, and alphas, respectively, and have the general form characteristic of evaporation spectra. The fast particles, mostly protons, exhibit energy and angular distributions similar to those previously found for heavier elements using nuclear cascade theory. This work was performed under the auspices of the U. S. Atomic Energy Commission.

P2. An Experimental Ion Source for the 184-inch Cyclotron. Warren Fenton Stubbins, *University of California, Berkeley.*—A PIG type ion source was mounted in the center of the 184-inch cyclotron with extension lips placed on the dees to reduce the dee gap and aperture in the source region according to requirements established by calculations. The operation of the source and the nature of the cyclotron beam were

observed for various conditions of dee voltage, dee bias, source position, and the time sequence of ion injection. A pulse-wise increase of dee voltage at the ion injection time to achieve greater acceptance of ions was investigated. The restrictions imposed on the initial conditions for ions resulted in a decrease in the radial oscillation amplitude by a factor of 2 to 3. The beam current was comparable to that available from the conventional open arc source. The work was performed under the auspices of the U. S. Atomic Energy Commission.

P3. Angle and Energy Distributions of Charged Particles from the Cyclotron Bombardment of Ni and Ag by 200-Mev Protons. L. Evan Bailey, *University of California, Berkeley.*—Thin nickel and silver targets have been bombarded by the internal proton beam of the 184-inch synchrocyclotron. Nuclear track plates were used to detect the secondary particles. Absolute cross sections for the production of protons, deuterons, tritons, He^3, and alphas will be presented in the 2- to 70-Mev energy range as a function of angle. Particles were identified by momentum *vs* range. The momentum was determined by the bending in the cyclotron magnetic field. Absolute cross sections were determined by measuring the target's activity, and by comparing it with the activity of a target calibrated in the external cyclotron beam. These cross sections illustrate the relative importance of the cascade (knock-out) process and the evaporation process at different secondary particle energies. This work was performed under the auspices of the U. S. Atomic Energy Commission.

P4. Analysis of the Disintegration Products from the Reactions of 125-Mev Deuterons with Lithium Nuclei. F. C. Gilbert, *University of California, Berkeley.*—A thin lithium (92.5 percent Li^7, 7.5 percent Li^6) target was bombarded with the internal deuteron beam of the 184-inch cyclotron. The resulting fragments were detected in a row of nuclear track plates placed along a radial line from the target. An analysis of the tracks in the emulsions yielded the following information: (a) energy distributions for the production of various fragments from 0° to 70° from the beam direction, (b) the angular distribution of Li^8 nuclei in the reaction $H^2+Li^7\rightarrow H^1+Li^8$, (c) the range distribution of the alpha particles following the decays of Li^8 and B^8, (d) the electron pickup by Li^8 ions as a function of their velocity, (e) the range of Li^8 nuclei in emulsion. In addition, absolute cross sections are obtained for processes (a) and (b) by means of exposures in the monitored external beam of the cyclotron. This work was performed under the auspices of the U. S. Atomic Energy Commission.

P5. External Proton Beam at the Cosmotron.* O. Piccioni, D. Clark, R. Cool, G. Friedlander, and D. Kassner, *Brookhaven National Laboratory.*—A system for ejection of protons from the Cosmotron by magnetic deflection has been devised.[1] After rf turnoff, the beam passes through a Lucite target which causes a decrease in orbit radius of about 4 inches in the next revolution. The beam then passes through a 1 in.×3 in. gap in a 30 in. long electromagnet placed near the inner edge of a straight section without having previously been disturbed by the magnet's fringing field. The protons are deflected outward by about 3° and arrive near the outer edge of the next straight section where they are given an additional outward deflection by a second magnet. Tests with the first magnet in place have produced at the position of the second magnet a proton beam about half the intensity of the circulating beam and with a cross section of about 1½ in.×5 in. The system can be used with either sharp or slow rf turnoff, thus preserving for the external beam the choice of time spreads between 1 and about 25 milliseconds now available with the internal beam.

* Research performed at Brookhaven National Laboratory, under the auspices of the U. S. Atomic Energy Commission.
[1] A substantially similar system has been independently proposed for the Bevatron by B. Wright, Rev. Sci. Instr. 25, 429 (1953).

P6. Nuclear Interactions of Cosmic Rays in Aluminum.* W. W. Brown,† *University of California, Berkeley.*—A method of detecting and observing cosmic-ray nuclear interactions in thin metal foils is described. Five aluminum foils, from 5 to 70 mg cm^{-2} thick×20×23 cm mounted horizontally in a cloud chamber, form the cathodes of a proportional counter system. The anodes are 3-mil tungsten wires strung between the foils. The gas, argon saturated with isoamyl alcohol, is common to the cloud chamber and counter system. Amplified pulses from the counters trigger the expansion of the chamber and cut off the high voltage rapidly enough so that the positive ions generated by the triggering particles are still in position for track formation. The amplifier bias is set high enough to favor observing heavily ionizing particles. Nuclear interactions occurring in the gas and foils at sea level are observed. Their absolute rate of occurrence in argon, 0.52 hr^{-1} per gram atom, agrees with previous measurement. The ratio of the rates in Al and A, when corrected for absorption effects of the foils, is about the same as the ratio of the geometric nuclear areas.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at North American Aviation, Inc., Downey, California.

P7. Some Results on Heavy Charged Mesons. R. Armenteros, B. Gregory, P. Hendel, A. Lagarrigue,* L. Leprince-Ringuet, F. Muller, and C. Peyrou, *Ecole Polytechnique, Paris.*—The results to be presented were obtained at the Pic du Midi in the French Pyrenees (9000 feet), with two cloud chambers placed one above the other.[1] The upper is in a magnetic field 2500 gauss; the lower is a multiplate chamber containing 15 copper plates 1 cm thick. The nuclear interactions of the secondaries of fast $V^{\pm}$ particles in the lower chamber indicate a large majority of μ mesons among the positive secondaries, but a considerable proportion of π mesons among the negative secondaries. Most of the particles with π-meson secondaries could be hyperons. We observe a significant positive excess for the slow charged $V^{\pm}$ particles (time of flight 1 or 2×10^{-9} sec) and a very large (27 to 1 or 2) positive excess for the S particles (time of flight larger than 5×10^{-9} sec). From the study of slow $V^{\pm}$ mesons and S particles we conclude the existence of two kinds of K particles with μ-meson secondaries. One is the $K_{\mu}{}^1$ which has a mass of 914±18, probably a two-body decay, and a positive charge. The other has a shorter mean life, a three-body decay, and probably a larger mass.

* Now at the University of California.
[1] Gregory, Lagarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento **II**, 292 (1954), and Report of the Padua Conference (to be published).

P8. Analysis of Charged *V* Events.* W. H. Arnold, J. Ballam, A. L. Hodson, R. Ronald Rau, George T. Reynolds, S. B. Treiman, and V. A. Van Lint, *Princeton University.*—Two interesting cases of V^+ events have been observed in a double cloud chamber operated at Echo Lake, Colorado (10 600 feet). Event 161–48942 consists of a charged particle, not visible in the upper chamber, which comes to rest in the second plate of the lower chamber and decays. The secondary then proceeds back up into the upper chamber and is visible for 33 cm. The secondary momentum is 145±5 Mev/c. Assuming it is a μ meson its momentum at the point of decay must have been 220±5 Mev/c, which is close to the value for p^* for the $K_{\mu}{}^1$ particle. Event 164–50818 is a charged V whose secondary makes a star in the argon gas of the upper chamber. The primary has a momentum of 740±130 Mev/c and is lightly ionizing. It therefore is unlikely that it is a hyperon. The secondary track is short but preliminary measurements of its momentum indicate that although it could be part of a charged τ decay it is more likely that it belongs to a

θ^+.[3] A general analysis of charged V events will also be presented.

* Supported by the Office of Naval Research and U. S. Atomic Energy Commission.
[1] Gregory, Lagarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento **II**, 292 (1954).
[2] Hodson, Ballam, Arnold, Harris, Rau, Reynolds, and Treiman, Phys. Rev. (to be published).

P9. Specific Ionization of High-Energy Electrons.* W. C. BARBER, *High-Energy Physics Laboratory, Stanford.*—The measurements of specific ionization described previously[1] have been improved in accuracy and extended to lower electron energies. The improved accuracy results from tests of the Faraday cup which indicate that its absolute error is under 2 percent while relative errors from changes in primary energy are less than 0.5 percent. Measurements over the energy range 1–35 Mev were made in H_2, He, and N_2. At minimum ionization, the gases showed 7.58, 6.16, and 5.34 ion pairs per cm at N.T.P., respectively. If the data are compared with the theory of energy loss, using constants given by Sternheimer[2] and taking into account the size of the ion chamber, the number of electron volts to produce an ion pair is calculated to be 38.5, 44.3, and 34.4, respectively. The relativistic increase in ionization agrees with the calculated increase in energy loss within 1 percent for N_2, but is a few percent less for He and H_2. Calculations indicate that this discrepancy may result from production of Čerenkov radiation.

* Supported by the joint program of the U. S. Navy (Office of Naval Research) and the U. S. Atomic Energy Commission.
[1] W. C. Barber, Phys. **93**, 942 (1954).
[2] R. M. Sternheimer, Phys. Rev. **88**, 851 (1952).

P10. Stripping Electrons from Accelerated O and Ne Ions.* EDWARD L. HUBBARD AND EUGENE J. LAUER, *University of California, Berkeley.*—Electrons were stripped from O and Ne ions accelerated by the 4-Mev Van de Graaff by passing the ions through a ¼-in.-diam., 20-in.-long tube filled with gas. Magnetic deflection was used to select the energy and charge of the incident ions and to determine the distribution of ionic charges in the stripped beam. Gas was admitted to the center of the tube and pumped away from both ends so that it was not necessary for the beam to pass through any foils. As the pressure was increased, the peak of charge distributions first shifted toward higher charges and then became constant as equilibrium was established between capture and loss of electrons. The pressure of argon at the center of the tube required for equilibrium was 40μ, corresponding to a thickness of 3.5×10^{16} atoms cm^{-2}. At equilibrium in argon the average ionic charges were

3.3-Mev O	6.1-Mev O	8.7-Mev O	3.1-Mev Ne	7.1-Mev Ne	10.3-Mev Ne
3.5	4.8	5.2	3.3	4.9	6.0

The charge distributions were bell-shaped with a width at half-maximum of 1.8. Little or no dependence on the stripper gas was observed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

P11. Analysis of Electron Stripping Data.* ROBERT L. GLUCKSTERN, *Yale University.*†—The stripping experiments in the preceding abstract have been compared with the predictions of a model due essentially to Bell[1] and originally applied to the capture and loss of electrons for fission fragments in gases. For lighter ions it appears desirable to modify the capture and loss cross sections to take account of the possibility of loss or capture of two or more electrons in a single stripper atom. The results for the dependence of the average charge on ionic atomic number and on energy are in good agreement with the experiments, and the predicted charge-state widths at half-maximum are all about 2.3, slightly larger than observed. A slightly increased average charge is predicted for strippers of higher atomic number. The observed variation of charge distribution with stripper thickness was converted into capture and loss cross sections on the assumption of single-jump events, and the results agreed reasonably well with those predicted. Double-jump events cannot be ruled out by the experiment, and there is some slight indication that they are present.

* This work was supported by the U. S. Atomic Energy Commission.
† This work was performed at the University of California, Berkeley.
[1] G. I. Bell, Phys. Rev. **90**, 548 (1953).

P12. Absolute Cross Section for the Reaction $C^{12}(\gamma,n)C^{11}$.* W. GEORGE, W. BARBER, AND D. REAGAN, *High-Energy Physics Laboratory, Stanford.*—Stacked foils were exposed to the direct beams of both the Mark II (38-Mev) and Mark III (270-Mev) linear accelerators, to obtain the activation curve for the reaction in the energy range 18–250 Mev. The shape of the cross-section curve was found by the photon-difference method. The threshold and peak characteristics compare reasonably with previous results,[1] but the curve has a high-energy tail extending even beyond 38 Mev. The shape of the tail is not well known, but the total effect is unlikely to be due to meson production. The value of the total cross section up to 38 Mev, $\int\sigma(k)dk$, was found to be 0.0505 ± 0.002 Mev-barns, with a peak at 22.5 Mev of 7.5 millibarns; up to 25 Mev, 0.0293; and up to 250 Mev, $\sim$0.060.

* Supported by the joint program of the U. S. Navy (Office of Naval Research) and the U. S. Atomic Energy Commission.
[1] Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953).

P13. Fission of Bismuth by 22-Mev Deuterons.* A. W. FAIRHALL, *University of Washington.*—High-purity (99.998 percent) bismuth metal bombarded with 22-Mev deuterons is being studied by radiochemical techniques for possible fission products. Activation analysis shows uranium and thorium absent in detectable amounts. Elements between zinc and barium are being examined. Some show activities which must surely come from traces of impurity in the target. Others, such as strontium, yttrium, and palladium, show activities which can only be fission products. These yields are very low, corresponding to cross sections of the order of 10^{-31} cm^2.† Preliminary results indicate a sharply rising fission-yield curve in the region of mass numbers 92 and 93, with a dip occurring at mass number 105. The indication so far is that the mass-yield curve is rather narrow, and possibly asymmetric. The latest results, and their correlation with Fong's theory of fission,[1] will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
† Preliminary studies were made with 15-Mev deuterons at *M.I.T.* At this energy the yields were a factor of about 20 lower.
[1] P. Fong, Phys. Rev. **89**, 332 (1953); privately circulated notes.

P14. The Decay of Bi^{207}. D. E. ALBURGER AND A. W. SUNYAR, *Brookhaven National Laboratory.**—Bi^{207} has been found to decay by electron capture accompanied by gamma rays of energies 570 ± 2 kev, 1.0639 Mev, and 1.78 ± 0.01 Mev having relative transition intensities of 1:0.90:0.10 and K-conversion intensities of 1.7, 8.2 and 0.022 electrons per 100 disintegrations, respectively. Electron capture branches 90 percent to the $i_{13/2}$ state at 1.634 Mev and 10 percent to a level at 2.35 Mev. The latter branch proceeds by L capture only as shown from the x-ray spectrum in coincidence with $1.78+0.57$ sum pulses. This information places the decay energy to the 2.35-Mev level at 50 ± 40 kev and the total Bi^{207} decay energy at 2.40 ± 0.04 Mev. The 1.78-Mev transition has a K-conversion coefficient of 2.4×10^{-3} in agreement with $E2$. Angular correlation experiments confirm the $1.06-0.57$, $13/2\rightarrow5/2\rightarrow1/2$ cascade but the $1.78-0.57$ cascade shows an approximately isotropic distribution when measured using a 50 μC liquid source of $BiSO_4$ in dilute H_2SO_4. We assume that the latter correlation is washed out by electronic effects associated with electron capture. An

investigation of the 1.78−0.57 correlation is now being made with an electroplated source. All other data are consistent with an assignment of $h_{9/2}$ to the 2.35-Mev level. A spin $\geq 7/2$ for this state is supported. Fast coincidence techniques have been used to show that the 0.57 Mev level has a half-life of $<4\times10^{-10}$ sec.

* Under contract with the U. S. Atomic Energy Commission.

P15. Gamma Rays Accompanying Spontaneous Fission of Cf^{252}. HARRY R. BOWMAN AND LLOYD G. MANN, *University of California, Livermore.*—The gamma-ray spectrum in coincidence with Cf^{252} spontaneous fissions has been measured using a source of 113 fissions per minute. A parallel plate ionization chamber and NaI(Tl) crystals were used to drive a coincidence circuit of one-microsecond resolving time. The sodium iodide crystals ranged in size from 1½ inch diameter × 1 inch to 3×2 inches and were corrected for pulse height distribution by the method used by Gerhart.[1] The gamma spectrum extends to about 5 Mev, with an average energy of 1.2 Mev. The total energy release via gamma radiation is 14±2 Mev per fission, indicating an average of 12 gamma rays per fission. This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Gerhart, Carlson, and Sherr, Phys. Rev. **94**, 917 (1954).

THURSDAY MORNING AT 9:00

1 Le Conte Hall

(K. MACKENZIE, presiding)

Invited Paper

Q1. Electron Scattering and Nuclear Structure. R. HOFSTADTER, *Stanford University.* (30 min.)

Contributed Papers

Q2. Theory of Nuclear Excitation in Inelastic Electron Scattering.* C. J. MULLIN AND E. GUTH, *University of Notre Dame.*—When nuclear excitation is induced by electron bombardment, the inelastically scattered electrons are always accompanied by electrons which have lost energy by bremsstrahlung. The inelastically scattered electrons can be observed only if the electron energy is sufficiently high so that the inelastic peaks (peaks in the energy distribution of the electrons scattered through a fixed angle) rise well above the background of "bremsstrahlung electrons." Recently, Hofstadter *et al.*[1] at Stanford have observed inelastic peaks in the energy distributions of 190-Mev electrons scattered on Be^9 and C^{12}. A theoretical study of the inelastic scattering process has been made in an attempt to deduce the properties of the excited levels of the scattering nuclei from the experimental scattering data. Definite conclusions about the spin and parity of an excited level cannot be made unless some assumptions are made about the form of the nuclear wave functions. In preliminary calculations, the inelastic scattering cross section has been evaluated by a method similar to that developed by Schiff;[2] nuclear wave functions of the harmonic oscillator type suggested by the shell model have been used.

* Supported in part by the Office of Naval Research.
[1] McIntyre, Hahn, and Hofstadter, Phys. Rev. **94**, 1084 (1954). J. A. McIntyre and R. Hofstadter, Abstract I-1, Seattle Meeting Am. Phys. Soc., July, 1954.
[2] L. I. Schiff, Phys. Rev. (to be published).

Q3. Phase Shift Analysis of High-Energy Electron Scattering.* D. G. RAVENHALL AND D. R. YENNIE, *Stanford University.*—Further results of a phase shift analysis of high-energy electron scattering[1] will be reported. Previously, the experimental data of Hofstadter *et al.* on gold at several energies[2] have been compared with cross sections obtained by using a "smoothed uniform" charge distribution.[2] The effect of altering the central charge density has now been investigated, in an attempt to improve the agreement with these experiments, and in order to examine the extent to which the experiments determine the charge distribution. Some results will also be presented for other nuclei whose distortion (i.e., intrinsic quadrupole moment) is small enough that the assumption of a spherically symmetrical charge distribution is justified.

* Supported in part by the Office of Scientific Research, Air Research, and Development Command.
[1] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).
[2] Hofstadter, Hahn, Knudsen, and McIntyre, Phys. Rev. **95**, 512 (1954).
[3] D. G. Ravenhall and D. R. Yennie, Phys. Rev. (to be published).

Q4. A Modified Born Approximation for Electron Scattering Calculations.* D. R. YENNIE, D. G. RAVENHALL, AND B. W. DOWNS, *Stanford University.*—It has been shown previously that for heavy elements the Born approximation is inadequate for calculating high-energy electron scattering.[1] However, after the problem of scattering in a central potential has been solved exactly (by numerical methods), additional effects can be treated by perturbation theory. Since the unperturbed scattering waves are known only through their partial wave decomposition, this method leads to a tedious, though straightforward, computation. We have found an analytic approximation to the complete unperturbed scattering wave which restores the perturbation calculation to the simplicity of the Born approximation; the approximation is good in the neighborhood of the nucleus. In this region the approximate function is very nearly a plane wave with normalization and wave number altered from that of the incident wave; in addition the wave fronts are slightly curved. This modified Born approximation will be used to estimate the sensitivity of electron scattering to small changes in the radial charge distribution.

* Supported in part by the Office of Scientific Research, Air Research, and Development Command.
[1] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).

Q5. Electric Quadrupole Effects in Scattering of High-Energy Electrons by Heavy Nuclei.* B. W. DOWNS, D. G. RAVENHALL, AND D. R. YENNIE, *Stanford University.*—Using a modified Born approximation,[1] we have calculated the contributions to the differential scattering cross section which arise from the static quadrupole moment and from the collective electric quadrupole transitions[2] (excitation of low-lying collective rotational states of the target nucleus[3]). For nuclei having large intrinsic quadrupole moments these contributions partially smooth the diffraction wiggles in the scattering curves calculated by the method of Yennie *et al.*;[4] the theoretical curves are thus brought into better agreement

with the experimental data.[5] The quadrupole charge distribution and the extent to which its details affect the scattering cross section will be discussed. Results will be presented for scattering of 183-Mev electrons by tantalum.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.
[1] Yennie, Ravenhall, and Downs, preceding abstract.
[2] L. I. Schiff, Phys. Rev. **96**, 765 (1954).
[3] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selsk., Mat.-Fys. Medd. **27**, 16 (1953).
[4] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).
[5] B. Hahn and R. Hofstadter, paper presented at this meeting.

Q6. W.K.B. Approximation to Phase Shifts.* S. P. HEIMS, D. R. YENNIE, AND D. G. RAVENHALL, *Stanford University.*—The computing time required to evaluate exactly the phase shifts for the nuclear electron scattering[1] at very high energies increases roughly as the square of the energy. For this reason the W.K.B. approximation for the phase shifts is being reconsidered. Using this approximation, E. Baranger[2] has obtained cross sections at 150 Mev for mercury that agree well with those obtained by the exact method, and the accuracy of the W.K.B. approximation improves as the energy increases. The phase integral is evaluated numerically rather than by the analytic approximation used by Baranger. Phase shifts and cross sections obtained by this method will be compared with those obtained by the exact method.

* Supported in part by the Office of Scientific Research, Air Research and Development Command.
[1] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).
[2] E. Baranger, Phys. Rev. **93**, 1127 (1954).

Q7. On the Radiative Correction to Electron Scattering.* H. SUURA, *Stanford University.*—The radiative correction to the high-energy electron scattering by heavy nuclei due to the one-virtual-photon processes is examined for all orders in the Born approximation with respect to the external field. The terms associated with the infrared catastrophe can be separated out quite generally, and are expected to give the same fractional decrease in transition probability as in the first Born approximation. This assumes that the elastic scattering is a continuous function of the distance from the energy shell; this is true for a non-Coulomb potential and is being investigated in the Coulomb case. The magnitude of the remaining terms is also being calculated in the second Born approximation.

* Supported by the Office of Scientific Research, Air Research, and Development Command.

Q8. Nuclear Dispersion Contribution to High-Energy Electron Scattering.* L. I. SCHIFF, *Stanford University.*—In the calculation of high-energy electron scattering from nuclei, the interaction may be divided into a static part that arises from the expectation value of the nuclear Coulomb field, and a dynamic part that takes account of the existence of excited states of the nucleus. The static part gives rise to elastic scattering and can be treated numerically for any assumed charge distribution, to all orders in the interaction.[1] The dynamic part gives rise to inelastic scattering in first order, and to dispersive contributions to both elastic and inelastic scattering in second order. These contributions involve sums over virtual intermediate states of the nucleus; they are are readily formulated but cannot be evaluated in closed form. An estimate of the magnitude of the dispersion terms is made with the help of the closure relation for the nuclear states. It is found to be small, although not negligible, in some cases of physical interest.

* Supported in part by the Office of Scientific Research, Air Research, and Development Command.
[1] Yennie, Ravenhall, and Wilson, Phys. Rev. **95**, 500 (1954).

Q9. High-Energy Electron Scattering in Rh, Ta, W, and U.† BEAT HAHN AND ROBERT HOFSTADTER, *Stanford University.*—Recent improvements in experimental technique have made it possible to measure more accurately the angular distribution of high-energy electrons (180 Mev) scattered by heavy and medium nuclei. Small differences in scattering cross sections of two nuclei can be established by measuring ratios of counting rates at each scattering angle. Scattering ratios of gold with respect to hydrogen have been measured, as well as ratios with respect to Rh, Ta, W and U. Ta, W, and U definitely show less pronounced diffraction wiggling in the angular distribution than Pb^{208}, Au, and Bi. It is fairly difficult to fit the experimental results for Ta, W, and U with phase shift calculations to a spherically symmetric charge distribution. A possible explanation of these relatively smooth angular distributions may involve nuclear-quadrupole effects.*

† Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command. Also aided by a grant from the Research Corporation.
* Downs, Ravenhall, and Yennie, paper presented at this meeting.

Q10. Electrodisintegration of the Deuteron.* V. Z. JANKUS, *Stanford University.*—Calculations have been made on the disintegration of the deuteron in high-energy electron impact. With increase of momentum transfer the inelastic cross section increases at the expense of the elastic, while the sum of the two remains approximately equal to the Mott cross section. The energy spectrum of the scattered electron has been obtained using the Møller potential. In this calculation it was necessary to take account of the proton-neutron interaction in the final S state. The influence of this interaction on the states of higher angular momentum has been found to be much smaller. The results indicate that the cross section is sensitive to the effective range of proton-neutron forces, especially at high momentum transfers, such as produced by 300-Mev electrons scattered at 60°.

* Supported in part by the Office of Scientific Research, Air Research, and Development Command.

THURSDAY AFTERNOON AT 1:30

310 Le Conte Hall

(PAUL KIRKPATRICK, presiding)

Division of Electron Physics

Invited Papers

R1. Physical Properties of Germanium Surfaces. C. G. B. GARRETT, *Bell Telephone Laboratories.* (30 min.)

R2. Experiments at Very Low Pressures. D. H. ALPERT, *Westinghouse Electric Corporation.* (30 min.)

R3. Radio Astronomy. RONALD N. BRACEWELL, *Sydney Radio Physics Laboratory* (now visiting University of California, Berkeley). (30 min.)

R4. The Upper Atmosphere. JOSEPH KAPLAN, *University of California, Los Angeles.* (30 min.)

THURSDAY AFTERNOON AT 1:30

4 Le Conte Hall

(J. R. RICHARDSON, presiding)

Contributed Papers

S1. Radioactivity of Co^{57}. BERND CRASEMANN AND D. L. MANLEY,* *University of Oregon.*—By the reaction $Mn^{55}(\alpha,2n)$, Co^{57} (270 day) has been prepared, separated chemically, and its disintegration investigated with a magnetic lens spectrometer. A helical baffle permitted a study of the low energy positron spectrum without interference from conversion electrons. Preliminary results of this work indicate that Co^{57} decays to two excited states of Fe^{57} by positron emission and electron capture. From the conversion electron spectrum, the energy of two previously known gamma rays was determined as 0.133 ± 0.002 and 0.119 ± 0.002 Mev, with relative gamma intensities of 3 and 97 percent. These transitions presumably are magnetic quadrupole and electric dipole, respectively, in accordance with conversion coefficient measurements of Alburger and Grace.[1] The K-capture/positron ratio for transitions to the second excited state of Fe^{57} is $(6.7\pm3.5)\times10^2$. Two positron groups have maximum energies 0.312 ± 0.020 and 0.194 ± 0.010 Mev, relative abundance 70 and 30 percent, and log(ft) values of approximately 8.1 and 7.6. A new half-life measurement is in progress. A tentative decay scheme is proposed.

* Now at Department of Radiological Physics, University of Rochester.
[1] D. E. Alburger and M. A. Grace, Proc. Phys. Soc. (London) **67A**, 280 (1954).

S2. Radioactivity of Sn^{109}. M. D. PETROFF, S. W. MEAD, AND W. O. DOGGETT, *University of California, Berkeley.*—An 18-minute radioactivity produced by bombarding CdS enriched in Cd^{106} with 15-Mev alphas has been assigned to Sn^{109}. The bombarding energy was chosen such as to favor strongly the reaction $Cd^{106}(\alpha,n)Sn^{109}$. The analysis was based primarily on the observation of the chemically separated Sn in a magnetic lens beta-ray spectrometer. Two internal conversion peaks corresponding to γ rays of energies 0.073 and 0.678 Mev were found to decay with an approximately 18-minute half-life, and the related growth of a peak identified with the 0.205 Mev γ of In^{109} was also observed. After the decay of the 18-minute component, the remaining spectrum included the two strongly converted γ-rays observed by McGinnis.[1] The half-lives, energies, and K/L ratios were in agreement with McGinnis' findings. Other data, obtained with a trochoid analyser and a continuously recording pulse-height analyzer, indicate that both K-capture and positron emission are involved in the Sn^{109} decay. The presence of other short lives, such as the 50-minute Sn^{108}, makes accurate determination of the half-life difficult. Our present estimate is 18 ± 2 minutes. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] C. L. McGinnis, Phys. Rev. **81**, 739 (1951).

S3. Proton Bremsstrahlung.* HANS MARK, CLYDE MCCLELLAND, AND CLARK GOODMAN, *Massachusetts Institute of Technology.*—The bremsstrahlung emitted when protons are scattered by nuclei is an important background effect in electric excitation experiments.[1] This process has been investigated in some detail using protons between 1 and 3 Mev. The emitted bremsstrahlung spectrum, the yield of 150-kev photons as a function of proton energy and the cross section for the production of 150-kev photons have been determined for various materials. The results are in reasonable agreement with a semi-classical calculation based on the treatment of Landau and Lifschitz.[2] It has also been possible to observe x-rays characteristic of absorbers placed between the target and the detector which are caused by the photoelectric absorption of high energy bremsstrahlung photons.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] C. Zupancic and T. Huus, Phys. Rev. **94**, 205 (1954).
[2] L. Landau and E. Lifshitz, *The Classical Theory of Fields* (Addison Wesley Press, Cambridge).

S4. N–P Scattering at 20 Mev.* R. B. DAY, R. L. MILLS, J. E. PERRY, JR., AND F. SCHERB, *University of California, Los Alamos Scientific Laboratory.*—Using the $T(d,n)He^4$ reaction as a source of high-energy neutrons, we have measured the neutron total cross section of hydrogen in a transmission experiment. The detector was a stilbene scintillation counter biased to count neutrons of energy greater than 10 Mev and placed at a distance of 160 cm from the neutron source. The hydrogen was contained in a pressure vessel 1 meter long at a pressure of 4000 psi. The number of moles of hydrogen in this vessel was known to ±0.1 percent. An identical evacuated cell was used to obtain the "sample-out" counting rate. The background produced by neutrons scattered from the room and surrounding objects was of the order of 0.5 percent, while the counting rates with the tritium gas target evacuated were of the order of 0.1 percent. The preliminary value of the total cross section is $\sigma_t=0.495\pm0.003$ barn at a neutron energy of 19.655 ± 0.035 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

S5. Multiple Scattering of 2.5 Mev Positrons by 0.1 mil Gold Foil. L. GRODZINS, *Purdue University.*—An external beta ray spectrograph selects 2.5 ± 0.35-Mev positrons from a Ga^{66} source, and these are injected into the median plane of a 12-inch diameter cloud chamber illuminated over a $3\frac{1}{2}$-inch depth. A magnetic field bends them in an arc of 17 cm radius so that they strike a 0.1 mil gold foil in the chamber perpendicularly (within 15°). Projected scattering angles are measured with a reproducibility of about $\frac{1}{2}$°. The results of an examination at the first 1141 foil traversals are as follows:

Angle (degrees)	0–2	2–4	4–6	6–8	8–10	10–15	15–20	>20	Total
Experiment	437	251	197	116	60	58	6	16*	1141
Theory[1]	374	304	203	117	61	55†	15	12	1141

* In the previous examination of 10 430 foil traversals (see Phys. Rev. **94**, 758 (1954)) a search for large angle scatterings found 118 ± 11 scatterings >20° compared with the theoretical prediction of 111 for positrons and 201 for electrons of 2.5 Mev.
† Molière theory adjusted at angles >10° to take into account deviations from Rutherford scattering.
[1] G. Molière, Z. Naturforsch. **3A**, 78 (1948).

S6. Interaction of 4.1-Mev Neutrons with Nuclei.* M. WALT AND J. R. BEYSTER, *Los Alamos Scientific Laboratory.*—The differential cross sections for elastic scattering of 4.1-Mev neutrons from Be, C, Al, Ti, Fe, Zn, Zr, Cd, Sn, Ta, W, Au, Pb, and Bi have been measured using a geometry similar to that described previously.[1] Neutrons produced by the $H^3(p,n)He^3$ reaction were scattered by cylindrical samples and were detected with a biased scintillation counter. The detector, which was insensitive to gamma rays, was operated at three biases having neutron detection thresholds at about 2.0, 2.6, and 3.2 Mev. Inelastic collision cross sections were obtained by subtracting the integrals of the differential elastic cross

sections from the total cross sections. Listed below are the inelastic collision cross sections obtained with the highest bias.

Inelastic Collision Cross Sections

Element	σ_{in}	Element	σ_{in}	Element	σ_{in}
Be	0.57 ± 0.1	Zn	1.7 ± 0.2	W	2.4 ± 0.3
C	0.08 ± 0.1	Zr	1.8 ± 0.2	Au	2.7 ± 0.3
Al	$0.7\ \pm0.2$	Cd	2.1 ± 0.2	Pb	1.9 ± 0.3
Ti	$1.2\ \pm0.2$	Sn	2.1 ± 0.2	Bi	2.2 ± 0.3
Fe	1.55 ± 0.2	Ta	2.7 ± 0.2		

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] M. Walt and H. H. Barschall, Phys. Rev. **93**, 1062 (1954).

S7. Proton Scattering from N^{14}.* G. W. TAUTFEST, J. R. HAVILL, AND SYLVAN RUBIN, *Stanford Research Institute.*—The elastic scattering cross section of N^{14} for protons was measured at 152° (CM), from 1.3 to 1.9 Mev, using a thick target of melamine, and a high resolution magnetic spectrometer. Points were taken at energy intervals of about 20 kev. Complex resonance structure in the region between 1.5 and 1.8 Mev apparently corresponds to the three resonances at 1.55, 1.75, and 1.81 Mev in $N^{14}(p,\nu)O^{15}$ reported by Duncan and Perry.[1] The resonances are superimposed on a nonresonant yield approximately three times the Rutherford cross section. The cross sections at 1.43 Mev are 0.097 *b* for N^{14}, and 0.19 *b* for C^{12}, measured from the same profile curve. The carbon cross section agrees closely with that obtained by Jackson *et al.*[2] Further work is planned, using boron nitride targets.

* Supported by contract with Watertown Arsenal Laboratories.

[1] Duncan and Perry, Phys. Rev. **80**, 136 (1950).

[2] Jackson, Galonsky, Eppling, Hill, Goldberg, and Cameron, Phys. Rev. **89**, 365 (1953).

S8. A Fission Fast Counter Using the Gas Scintillation Principle. A. E. VILLAIRE AND L. F. WOUTERS, *University of California, Livermore.*—Fission fragments emitted from a uranium surface due to neutron bombardment, cause excitation events in a surrounding pure argon atmosphere. The ultraviolet radiation emitted by the decay of excited states is converted to blue light by a thin polystyrene film containing 3 percent tetraphenyl butadiene. The light pulse resulting from each fission event is detected by a 6292 photomultiplier tube, and is of such intensity that under average conditions the output pulse height is about 0.1 volt; the pulse width is 10^{-8} second or less. The pulse height ratio between fission pulses and the sea of background α pulses[1] is about 16:1. While the neutron detection efficiency is of the same order as for a proportional fission counter, the pulse resolution time is significantly shorter. The principal difficulty is the rapid poisoning of the argon gas, probably by the plastic converter; to circumvent this, our tests were conducted using continuous gas flow through the chamber. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] C. Eggler and C. M. Huddleston, Phys. Rev. **95**, 600(A) (1954).

S9. Elastic Scattering of 1.6-Mev Gamma Rays from Carbon. LUIS W. ALVAREZ, FRANK S. CRAWFORD, JR., AND M. LYNN STEVENSON, *University of California, Berkeley.*—Elastic scattering of 1.6-Mev gamma rays from carbon has been observed, at a scattering angle of 130°. Eighty curies of $Ba^{140}La^{140}$ provided about forty-five curies of 1.6-Mev gamma rays. A 15-kilogram ring-shaped carbon target located 47 inches from the source scattered gamma rays into a 4-by-4-inch sodium iodide counter. Uranium and lead absorbers shielded the crystal from the source. A ½-inch lead absorber surrounding the crystal eliminated pile-up from inelastic Compton scatters. An accurate 10^{-7} fraction of the radioactive source was placed at the average target position, and a 10-channel pulse-height analyzer was centered on the 1.6-Mev peak. Radiation scattered from the target showed a peak in the pulse-height spectrum having the shape and position corresponding to 1.6-Mev gamma rays. Lead absorbers attenuated the scattered radiation by the expected amount. The differential-scattering cross section was obtained by measuring the distance from source to target, the number of carbon atoms, the 10^{-7} dilution ratio, and the ratio of counting rates from scattered gamma rays and the 10^{-7} source. As a result, we obtain the classical Thomson differential cross section for carbon, 1.5×10^{-31} cm^2 ster^{-1}, with a 5-percent error due to counting statistics and a 25-percent error assigned to cover present uncertainties in systematic corrections. This work was performed under the auspices of the U. S. Atomic Energy Commission.

S10. A Millisecond Gamma Emitter from Protons on Ta. SHELDON D. SOFTKY, *University of California, Berkeley.*—A search for gamma emitters in the millisecond range of half life was conducted using the 32-Mev Berkeley proton linear accelerator. Foil targets of eighteen common elements were bombarded and the activity made in them followed between beam pulses with a gated scintillation counter. The only activity found of measurable yield was from Ta, and it exhibited a half life of 5.5 ± 0.3 milliseconds. Using a gated nine-channel pulse-height analyzer with the NaI(Tl) crystal counter, the excitation curve of this activity was measured and its gamma spectrum deduced. Gammas of 0.35 Mev and 0.22 Mev are indicated by the pulse spectrum, and no β's are present commensurate with this half life. Comparison of the excitation curve for this activity with those of Ta^{180} (8 hr) and W^{179} (30 m) leads to the tentative assignment of this decay to W^{180m}. As far as can be determined, this is the first known isomer with half life in the millisecond range. This work was performed under the auspices of the U. S. Atomic Energy Commission.

S11. *L*-Conversion in Pure *E*2 Transitions.* F. BOEHM, P. MARMIER, AND J. W. M. DUMOND, *California Institute Technology.*—A number of pure *E*2 transitions at low energies were studied with the axial focusing β-ray spectrometer using a momentum resolution of 1.5 parts in 1000. Conversion coefficients for the *LI*, *LII*, and *LIII* shells were measured with high accuracy. The results obtained for transitions between 50 kev and 200 kev, and $Z=59$, 72, and 74 are given.

* Research work supported by contract with the U. S. Atomic Energy Commission and the Office of Ordnance Research (U. S. Army).

S12. Energy Levels of Hf^{177}.* P. MARMIER, F. BOEHM, AND J. W. M. DUMOND, *California Institute of Technology.*—The decay of 6.8 *d* Lu^{177} has been studied with the curved crystal γ-ray spectrometer and the axial focusing β-ray spectrometer. In addition to the lines at 113 kev, 208 kev, and 321 kev, two weak transitions were found at 72 kev and 250 kev. The decay scheme was established with the help of coincidence measurements. The levels of Hf^{177} have the following energies: 112.97 ± 0.02 kev, 249.69 ± 0.04 kev, and 321.33 ± 0.04 kev. Multipole assignments are given for all transitions.

* Research work supported by contract with the U. S. Atomic Energy Commission and the Office of Ordnance Research (U. S. Army).

S13. Relative Stopping Powers for 20-Mev Protons.* C. P. SONETT† AND K. R. MACKENZIE, *University of California, Los Angeles.*—The stopping powers of Ni, Cu, Cb, Pd, Ag, Cd, In, Ta, Pt, Au, and Th relative to Al were measured using the 20.6 Mev external proton beam of the UCLA cyclotron. The measurements were made with sufficient precision so that a graph of ln *Z* *vs* stopping power per electron relative to aluminum showed some fluctuation from a linear relationship. For Cu and Ni the values differed by 2 percent from the values expected on the basis of a fit to a straight line through the mean of all values. The deviation for Th was 2.6 percent in the direction found by Kelley and Teasdale. Some suggestion is made that the difference between Cu and Ni could be due

to the differences in the electronic structures of the atoms and to the differences in the band structures of the metals.

* Supported by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at the Ramo-Wooldridge Corporation, Los Angeles, California.

S14. Gamma-Gamma Directional Correlation in the $Cl^{34} \rightarrow S^{34}$ Decay. HARRY E. HANDLER AND J. REGINALD RICHARDSON, *University of California, Los Angeles.**—The directional correlation between the 1.15- and 2.10-Mev gamma rays[1] which follow the decay of 33-minute Cl^{34} has been measured. Samples of Cl^{34} were made in the UCLA cyclotron by the (p,pn) reaction on NaCl. Sodium iodide scintillation counters with subsequent pulse-height discrimination were used. Preliminary analysis of the results of coincidence counting at five angles from 0° to 90° between the direction of emission of the two gamma rays using powdered crystalline sources is consistent with the assignments of spin 2 and even parity to both the first and second excited states of S^{34} and indicate that magnetic dipole radiation is favored over electric quadrupole radiation in the first transition. The correlation was unchanged when sources in water solution were used; this suggests that the interactions of the nuclei with external fields were small and did not attenuate the correlation when solid sources were employed.

* This work was assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Harold K. Ticho, Phys. Rev. **84**, 847 (1951).

THURSDAY AFTERNOON AT 1:30

1 Le Conte Hall

(F. A. JENKINS, presiding)

Contributed Papers

T1. Scintillation Studies on Activated Alkali Halides. T. H. ANDERSON, *U. S. Naval Radiological Defense Laboratory.*—Values for the decay times of activated alkali halide scintillators determined by response to individual ionizing events are not precise because the energy available is too small to give statistically reliable results. To overcome this, crystalline specimens were irradiated with a very short pulse of many electrons, thereby increasing the light output several hundred times. The apparatus consisted of a 7 JP oscilloscope gun with 40 kv post acceleration. The beam was swept across a slit to give pulses of the order of 10^{-9} second. The scintillations were followed by a 6292 photomultiplier connected directly to a 517 Tectronix oscilloscope which was triggered together with the deflecting signal. No time jitter was observed. Measurements of the traces give decay times of 0.260 μsec for NaI(Tl) and 0.180 μsec for KI(Tl) at room temperature. A search for a lag in the onset of luminescence was made by alternately sweeping a fast organic scintillator and an inorganic crystal. Evidence of a time lag was found and two possible explanations for this delay are offered. Both energy transport mechanisms and trapping may occur.

T2. Microwave Dielectric Measurements on Single Fibers. J. J. WINDLE AND T. M. SHAW, *Western Utilization Research Branch, Agricultural Research Service.*—Microwave techniques, which have proved successful at wavelengths of 3.25 and 10.0 cm for the determination of the complex dielectric constant of fiber bundles,[1] have been extended to include a wavelength of 1.15 cm, where for the first time measurements on a single wool fiber have proved to be feasible. Such measurements make it possible to compare directly the results of electrical and mechanical measurements on the same single fiber. In addition, the single-fiber technique has provided a convenient, rapid, and nondestructive method for the determination of average mass of adjacent 1-cm sections of the fiber along its length. Variations as large as 2-fold in mass per unit of length are sometimes encountered within a single wool fiber. With single fibers preliminary measurements have been made of the complex dielectric constant and its variation with sorbed water at $\lambda = 1.15$ cm. The results appear to be in accord with the relationship proposed by us[2] to account for the dielectric properties observed for wool-water systems at $\lambda = 3.25$ cm and $\lambda = 10.0$ cm.

[1] T. M. Shaw and J. J. Windle, J. Appl. Phys. **21**, 956 (1950).
[2] J. J. Windle and T. M. Shaw, J. Chem. Phys. **22**, 1752 (1954).

T3. Changes in Photoelectric Probability Factor Resulting from Surface Contamination of Aluminum. R. L. PERRY AND J. J. BRADY, *Oregon State College.*—Measurements have been made on an aluminum cathode concentric sphere photocell using the 2537 A line of the mercury arc as a light source. The Fowler-DuBridge method was used to analyze the photocurrent *vs* retarding potential curves from which a value of the probability factor α was obtained. Starting with a freshly evaporated surface of aluminum, successive curves were obtained after the surface was contaminated with residual gas. To contaminate the surface a copper trap in the system was heated for a short time, resulting in an increase in pressure. All measurements were made with a pressure less than 4×10^{-7} mm. The contamination decreased the work function by about 10 percent while the corresponding change in α was an increase of about 3 percent.

T4. Vacuum Deposition of Magnetic Alloy Films.* M. S. BLOIS, JR., *Stanford University.*—Thin magnetic films have been pr pared by vacuum evaporation in the thickness range, 1000 A to 50 000 A, and consisting of alloys in the iron-nickel and iron-cobalt systems. The magnetic properties—coercivity, saturation induction, and hysteresis loop form—have been observed, and the dependence of these properties upon the choice of magnetic materials and parameters of the evaporation process, has been studied. The change in alloy composition that takes place between the melting of the starting material and the final formation of the alloy film, has been studied for both the alloy systems above and will be compared with the behavior predicted on the basis of current theory. It has been found that a ferromagnetic film formed in the presence of a magnetic field has directional properties dependent upon this field. In particular, it has been possible to produce Permalloy films by evaporation with extremely square hysteresis loops. A general finding has been that these films have the properties characteristic of the bulk alloy, except for coercive force which is consistently higher for the films.

* This work was supported by the Office of Naval Research, and conducted at U. S. Naval Ordnance Laboratory, Corona, California.

T5. Absorption Bands of Rubidium in the Presence of Foreign Gases.* SHANG-YI CH'EN, ROBERT B. BENNETT, AND OLEG JEFIMENKO, *University of Oregon.*—The structureless absorption bands of rubidium caused by collisions with foreign gas molecules appearing in the neighborhood of certain mem-

bers of the principal series were investigated. When the temperature was 200°C or higher a band was observed at the short wavelength side of the resonance lines for all gases used. For H_2, He, Ne, N_2, and A a band was also observed at the short wavelength side of the second[1] and the third members of the series. For methane, ethane, propane, and butane a band appeared at the long wavelength side of each of the components of the first three doublets. The bands appearing near still higher members of the series were so close to the atomic lines that they were generally not resolved.

* Supported by the National Science Foundation.

[1] A part of the results for the second member of the Rb principal series had been given by Tsi-Ze Ny and Shang-Yi Ch'en, J. phys. et radium **9**, 169 (1938).

T6. Phase Change on Reflection from Multilayer Films. F. A. JENKINS AND D. R. SPECK, *University of California, Berkeley.*—Two disadvantages of the use of multilayer films on Fabry-Perot interferometers are the restricted wavelength range of high reflection and the relatively large phase shift. The latter is ten to twenty times as great as that for silver, and might be thought to constitute a serious bar to precision wavelength measurements. If it can be calculated with sufficient accuracy to permit a unique assignment of order numbers, however, it can be determined and corrected for just as is done for metal films. We have photographed the fringes in the iron arc spectrum, and applied the method of exact fractions to the secondary wavelength standards, using 9-layer films of zinc sulfide and cryolite. By comparison with the theoretical phase shifts computed by the matrix method, agreement is found for one particular assignment of orders to 0.01 of an order. This result is in agreement with that found by other investigators in the infrared,[1] and shows that it is feasible to use such films for wavelength determinations. When one is working over a wavelength range of more than 1000 A, however, metal films would be preferable.

[1] Rank, Shearer, and Wiggins, Phys. Rev. **94**, 575 (1954).

T7. Preliminary Report on the Quadrupole Moment of Niobium. D. R. SPECK AND F. A. JENKINS, *University of California, Berkeley.*—A study of the hyperfine structure in the spectrum of $Nb^{99}I$ has been undertaken in an attempt to measure the electric quadrupole moment of the niobium nucleus. Previous workers have concluded that to within the limits of accuracy of their experiment no quadrupole moment was detectable in niobium. However, the fact that this moment is different from zero has been established by recent nuclear resonance experiments on $KNbO_3$ in which the interaction of the nuclear electric quadrupole moment of niobium with the electric field gradient in the $KNbO_3$ molecule has been measured. In view of this latest result it was thought that a careful reinvestigation of the hyperfine structure in the niobium spectrum might be fruitful. Preliminary investigations on the line λ5271 ($^6F_{\frac{1}{2}}-{}^4D_{\frac{1}{2}}^0$) show within the probable error small deviations from the interval rule in the hyperfine structure of the $Hd^3\,5s^2\,{}^6F_{\frac{1}{2}}$ term. Fitting the observed intervals into the usual interaction formula yields the values $A=21.7\pm0.1$ mK for the magnetic splitting factor and $B=-0.0044\pm0.0027$ mK for the quadrupole coupling constant. Using this value for B and the h.f.s. formulas published by R. E. Trees, one obtains for the quadrupole moment $Q=-0.4\pm0.3\times10^{-24}$ cm². The error given is the standard deviation based on the internal consistency of the data. This value of Q is derived from measurements on only one line in the niobium spectrum.

T8. Penetration into Rarer Medium in Total Reflection of Microwaves. R. O. BRICK, J. J. BRADY, AND M. D. PEARSON, *Oregon State College.*—Two identical 45°–90°–45° prisms are mounted so that the distance between the two hypotenuse faces is adjustable. Microwaves in the 3-cm region are incident normal to one prism face. For a small separation between the prisms part of the power is transmitted through both and part is reflected at the first hypotenuse. Theory indicates that for high values of index of refraction, transmitted power polarized in the plane of incidence decreases more rapidly with prism spacing than power polarized perpendicular to the plane of incidence. For low values of index of refraction, n, the opposite is true. For a value of $n=1.732$ the decrease of transmitted power with distance is the same for both polarizations. The theory has been verified experimentally by using prisms of paraffin ($n=1.50$), sulfur ($n=1.90$), and salt ($n=2.43$).

T9. Cyclical Variations in the Effective Radiation Temperature of the Ozone Region. ARTHUR ADEL, *Arizona State College.*—Fluctuations both periodic and nonperiodic in ERTOR (Effective Radiation Temperature of the Ozone Region)[1] have been under systematic observation at Flagstaff, Arizona, since July, 1953. Of particular interest is the ERTOR oscillation, period ten weeks, which is superimposed upon the annual variation.

[1] Arthur Adel, in *The Atmospheres of the Earth and Planets*, edited by G. Kuiper (University of Chicago Press, Chicago, 1952), Chap. X. R. M. Goody, *The Physics of the Stratosphere* (Cambridge University Press, Cambridge, 1954), pp. 108–109.

THURSDAY AFTERNOON AT 1:30

3 Le Conte Hall

(W. A. WILDHACK, presiding)

Invited Paper

U1. Instrumentation Research at the National Bureau of Standards. W. A. WILDHACK, *National Bureau of Standards.* (30 min.)

Contributed Papers

U2. A Long-Wavelength X-Ray Reflection Microscope.* J. F. MCGEE, *Stanford University.*—The use of wavelengths of the order of ten angstroms (instead of the usual one or two) permits a larger field of view while enhancing the light-gathering power. The importance of surface irregularities becomes less, and materials of low atomic number become observable. A quantitative determination of the field aberrations of a system composed of two spherical mirrors was made by ray tracing, using an IBM Card-Programmed Calculator. Examination of the field *vs* resolution curves shows that the theoretical width of field is about 100 microns for a resolution of at least 1500A. Such a microscope was constructed in-

corporating two uncoated silica mirrors and an aperture stop so placed as to minimize image obliquity. The system was irradiated with aluminum K and continuous radiation from a tube with a focal spot intermediate in size between those of commercially available tubes and so-called "micro-focus" tubes. With dry helium replacing air in the optical path, photography of magnified images required exposures from five minutes to one-half hour.

* Supported by a grant-in-aid from the American Cancer Society upon recommendation of the Committee on Growth of the National Research Council.

U3. A Metal Vacuum Joint Suitable for Field Emitters.* HOWARD H. PATTEE, JR., *Stanford University.*—A demountable, all-metal, ultra-high vacuum joint, useful at pressures of 10^{-10} mm Hg, has been developed for a field-emission, point-focus x-ray tube. The joint consists of stainless-steel knife edges clamped into a copper gasket with special flanges, and it can be dismounted and reassembled in a few minutes. The entire joint can be baked out at 500°C. When the system is shut off at 10^{-10} mm Hg, no pressure rise is observed on a Bayard-Alpert ionization gauge in a week. The volume of the system is 0.2l, and the total length of seal is 10 cm. Field emitters or other electrodes can be introduced through these joints, and because the joint is slightly flexible, some adjustment of the electrodes inside the vacuum is possible. The continuous operation of field emitters under different conditions will be discussed.

* Supported by a grant-in-aid from the American Cancer Society upon recommendation of the Committee on Growth of the National Research Council.

U4. A High-Sensitivity Mass Spectrometer.* J. H. REYNOLDS, *University of California, Berkeley.*—A 4½-inch-radius, 60°-deflection, single-focusing, mass spectrometer, designed especially for isotope abundance measurements on small gas samples, has recently been completed. Emphasis in the design was placed on high sensitivity and low background. The envelope is of Pyrex and includes a total volume of about 2 liters. The analyzer tube is 20 mm Pyrex, internally silvered by chemical deposition where necessary; a section of this tube is bent and flattened so as to pass between the wedge-shaped poles of an electromagnet. Source and collector assemblies are compressed onto quartz (ion source) or Pyrex (collector) alignment rods by Inconel X springs, and terminate in stainless steel tubes which grip the inner surface of the glass analyzer tube. Errors in relative alignment of the metal and glass parts of the apparatus are compensated by electrostatic deflection. The ion source is of standard electron-bombardment design. The collector includes a 9-stage Allen-type electron multiplier preceded by a magnetically operated shutter, on which the beam can be collected for direct electrical measurement when desired. Spectrometer and sample system are both mounted on adjacent transite oven bases, above which permanent bake-out ovens are suspended. Identical mercury diffusion pumps and associated traps exhaust these systems through all-metal vacuum valves mounted in the bake-out region.

* This work has been supported by the Office of Naval Research.

U5. Performance Data for a High-Sensitivity Mass Spectrometer.* J. LIPSON AND J. H. REYNOLDS, *University of California, Berkeley.*—With 0.012-in. source slits and 0.024-in. collector slit, adjacent xenon peaks are flat-topped and resolved. Using 375°C bake-out and without rf heating of the ion source, operating pressures as low as 5×10^{-10} mm Hg have been achieved in 24 hours. Sensitivity measurements have seen made with argon and xenon samples of about 10^{-5} cc STP. Operating the spectrometer in the conventional way a "flow sensitivity," defined as electrons or ions out at the collector per atom in., is measured. Operating the machine with exhaust valve closed and the total sample admitted to the tube, a "static sensitivity," defined as electrons or ions to the collector per second per sample atom (and thus the inverse of the mean-life of sample atoms before excursions to the collector) is measured. For 5-ma source current and 320 volts per multiplier stage, we find as typical for xenon: multiplier gain 10^4, flow sensitivity 30 electrons per atom or 0.003 ion per atom, static sensitivity 3×10^{-2} electron per second per atom or 3×10^{-6} ion per second per atom, background noise equivalent to 1 ion per second or 3×10^5 sample atoms. This last figure represent the present detectability of the apparatus for xenon atoms. We find as typical for argon: multiplier gain 10^5, flow sensitivity 150 electrons per atom or 0.0015 ion per atom, static sensitivity 50 electrons per second per atom or 5×10^{-4} ion per second per atom, background at mass 36 (HCl) equivalent to 10^3 ions per second or 2×10^6 sample atoms.

* Work supported by the Office of Naval Research.

U6. Spin Echo Serial Storage Memory. A. G. ANDERSON, R. L. GARWIN, E. L. HAHN, J. W. HORTON, G. L. TUCKER, AND R. M. WALKER, *Watson Scientific Computing Laboratory (IBM).*—A series of short rf pulses applied to proton samples in liquids is stored, delayed and recovered in reverse or direct order by the spin echo method.[1,2] A maximum of the order of 1000 echo pulses has been obtained from a glycerine-water mixture. For the input, a pulse spacing of 20 μsec and pulse width of 7 μsec are typical parameters. Cycle repetition rate of the echo sequence is determined by the thermal relaxation time T_1 (~70 μsec for the glycerine-water mixture). For liquid samples with long relaxation times the upper limit on the number of observable echoes is determined, for a given number of protons, by the reduction of free precession coherence due to molecular self-diffusion. The application of a dc magnetic field H_c during storage and recovery times can be used (1) to eliminate fluctuation and attenuation of desired output echoes due to interaction between input pulses; (2) to eliminate mixtures of reverse and direct order echoes; (3) to permit any one of several serially stored groups of pulses to be immediately recalled; (4) to change the nuclear band width; and (5) to introduce information into the system.

[1] E. L. Hahn, Phys. Rev. **80**, 580 (1950).
[2] Initial research on such storage at Stanford has been done by S. Fernbach and W. Proctor.

U7. An Ultrasonic Technique for the Nondestructive Evaluation of Metal to Metal Adhesive Bonds. J. S. ARNOLD, *Stanford Research Institute.*—An ultrasonic technique has been developed for the non-destructive evaluation of structural adhesive bonds. A ferroelectric transducer is excited by a variable frequency driving current of constant amplitude, and the voltage developed across the transducer is displayed on an oscilloscope as a function of frequency. The voltage-frequency curve conveys information regarding the motional impedance of the system and hence the constraints that limit the vibration of the transducer. These constraints are imposed partly by the mechanical properties of the transducer and partly by the mechanical properties of the load (test specimen) to which it is coupled. The variation in the voltage-frequency curves that occur when the transducer is applied to satisfactory and defective test specimens can usually be correlated with the strength of the adhesive bonds, as indicated by subsequent destructive tests performed on the specimens. Block circuitry, typical oscilloscope patterns, and data on the correlation between destructive and non-destructive tests are presented.

U8. Aberrations and Fringing Effects in a Modified Siegbahn-Type Magnetic Spectrometer. S. A. BLUDMAN AND D. L. JUDD, *University of California, Berkeley.*—Obtaining high resolution with large aperture in a magnetic spectrometer with source and detector outside the field requires a study of non-linear corrections and of fringing effects on entering and

leaving the magnetic field. We write the trajectory equations so as to exhibit terms linear in the radial and axial oscillations which fix the focus,[1] non-linear terms which produce aberrations, and effects of the same order due to fringing. These equations are integrated analytically through the region of cylindrical symmetry by an iterative process correct through second-order in axial and third-order in radial oscillations. The principal fringing effects are to impose boundary conditions on the radial and axial trajectory slopes and to introduce an extrapolated field boundary. Approximation of the fringing field by a decreasing exponential is justified theoretically and experimentally. For a point object, values of the second and third radial field derivatives are obtained which minimize the aberrations in the presence of fringing. Focal surfaces, image sizes, and resolution curves will be presented for several radial apertures. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] D. L. Judd, Rev. Sci. Instr. **21**, 213 (1950).

U9. High-Resolution Magnetic Spectrometer.* SYLVAN RUBIN AND D. C. SACHS, *Stanford Research Institute*.—A high-resolution point-focusing magnetic spectrometer has been constructed for the analysis of the momentum distribution of elastically scattered protons from the surface layers of solid targets.[1] With a radius of curvature of 12 in. and a maximum field of 7000 gauss, it will analyze protons up to an energy of 2 Mev, with a momentum resolution of approximately 1 part in 3000, at an aperture of 0.0025 steradian. The theoretical limit of attainable resolution due to second-order aberrations[2] has been approached by adjustment of the field shape by means of mechanical adjustments of the gap and pole shape. The 30-amp, 140-volt regulated motor-generator current supply is stable to 1 part in 10^4. The magnetic field is compared with a reference permanent magnet, by means of a null-balance flip coil, with a sensitivity of 1 part in 10^4. This spectrometer design is adaptable to higher energies and larger aperture, for high-resolution nuclear spectrometry.

* Supported by contract with Watertown Arsenal Laboratories.
[1] S. Rubin and V. K. Rasmussen, Phys. Rev. **78**, 83 (1950).
[2] F. Shull and D. Dennison, Phys. Rev. **71**, 681 (1947); **72**, 256 (1947).

U10. A Charge-Exchange Accelerator. J. R. WOODYARD, *University of California, Berkeley*.—Following a suggestion of Alvarez[1] for an energy-doubling dc accelerator, a small machine has been constructed to produce one-Mev protons using a 500 kv dc source in order to test the method and to investigate design problems. A beam of protons at 30 kv is passed through a thin capture foil of aluminum or silicon monoxide with a thickness of about 10 micrograms per square cm. Approximately 20 percent of the incident protons capture two electrons and emerge as negative ions. Negative ion currents of 100 microamperes or more should be obtainable. The negative ions are accelerated by a high-voltage dc potential, are then passed through a stripping foil which changes them back to protons, and are finally accelerated again by the same potential. Both ion source and target are at ground potential. The 500-kv source is a 16-stage cascade rectifier voltage-multiplying circuit using 16 type 5825 rectifier tubes with rf filament heating. Initial performance data of the accelerator will be given.

[1] L. W. Alvarez, Rev. Sci. Instr. **22**, 705 (1951).

U11. Multiple Scattering Microscope for "Constant Sagitta" Measurements. STEPHEN J. GOLDSACK* AND GERSON GOLDHABER, *University of California, Berkeley*.—A precision microscope has been built with several novel features, and in particular with an automatic device to select cells for measurement of the mass of charged particles with a variable cell length technique. The pre-selected cell scheme is generated by a punched tape which carries the information. Work has been done to callibrate the P_1 cell scheme of Biswas *et al.*[1]: the mean value of the scattering per cell, taken over 460 cells, is 1.08 ± 0.04 microns after a 1-percent correction for noise. The results form a convenient set of data for checking the sampling errors. When calculations are made using the arithmetic mean and a cut off at $4D$ the relative standard error is well represented by the empirical formula $0.8/(N)^{\frac{1}{2}}$, for N observations. This leads to a relative error on the mass $1.9/(N)^{\frac{1}{2}}$. Further work is proposed to calibrate alternative cell schemes. The results of measurements of the mass of K-particles with the microscope will be described. It is interesting to note that in measurements of mass by this technique, a fortunate cancellation of effects makes the dependence of the measurements on the water content of the emulsions negligibly small.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Biswas, George, and Peters, Proc. Indian Acad. Sci. **38**, 418 (1953).

U12. Four-Inch Diameter Liquid Hydrogen Bubble Chamber. D. PARAMENTIER, A. J. SCHWEMIN, L. W. ALVAREZ, F. S. CRAWFORD, JR., AND M. L. STEVENSON, *University of California, Berkeley*.—A chamber constructed of a cylindrical brass wall 4 in. in diameter and 3 in. deep with glass windows has been operated successfully for a limited number of expansions. The chamber is maintained at a constant temperature by means of a pressurized bath of liquid hydrogen that is in contact with the brass wall of the chamber. In the latent state, the chamber is restrained from boiling by maintaining $\sim$6 atmosphere of pressure on the liquid hydrogen. To activate the chamber, the liquid is super heated by reducing the pressure on the chamber to one atmosphere. The particle beams are then pulsed into the chamber and the tracks photographed with a triggered stroboscopic light. The chamber remains at one atmosphere for about ten milliseconds, after which time the chamber is again pressurized $\sim$6 atmospheres. The chamber is then ready for another expansion cycle. Photographs will be shown of various tracks and events obtained with this and other liquid hydrogen chambers developed here. This work was performed under the auspices of the U. S. Atomic Energy Commission.

THURSDAY AFTERNOON AT 1:30

2 Le Conte Hall

(K. K. DARROW, presiding)

Post-deadline papers, if any

SUPPLEMENTARY PROGRAMME

SP1. II. Recombination in an Argon Shock Front.* JOHN W. BOND, JR., *Los Alamos Scientific Laboratory.*—If a shock in argon is sufficiently strong, ionization takes place. Behind the shock front there is a luminous region in which thermal equilibrium exists. In order to compute the recombination coefficient for a plasma consisting of electrons, neutral atoms, and singly-ionized atoms, a method of detailed balancing was used. Three equilibrium reactions are of importance: ionizing reactions between argon atoms, those between argon atoms and electrons, and the photoelectric reaction. Since the ionizing cross sections are known, their inverses may be readily computed. Maxwellian distributions were assumed to exist for all the particles at all times; this is probably valid because of the high temperatures and densities behind the shock front. Kramer's classical theory of radiative recombination was considered but gave values too high by about 10^4. Thomson's theory of three-body recombination gives answers of the right order of magnitude, but its region of applicability is limited. The recombination coefficient was used in computing the thickness of the shock front, and, because of the short duration of the latter, excitation reactions were not included.

* To be given at the end of Session C if the Chairman rules that time permits.

THURSDAY EVENING AT 7:30

Men's Faculty Club

(A. C. HELMHOLZ, presiding)

Banquet of the American Physical Society

After-dinner speech by R. T. BIRGE

Author Index to Papers Presented at the Berkeley Meeting

Adel, Arthur—T9
Alburger, D. E. and A. W. Sunyar—P14
Allen, William A., Joe M. Mapes, Earle B. Mayfield—C6
Alperovitch, Edward A. and J. Malcolm Miller—G13
Alpert, D. H.—R2
Alvarez, Luis W., Frank S. Crawford, Jr., and M. Lynn Stevenson—S9
Anderson, A. B. C.—C3
Anderson, A. G., R. L. Garwin, E. L. Hahn, J. W. Horton, G. L. Tucker, and R. M. Walker—U6
Anderson, C. D.—B2
Anderson, John D., Robert W. Kenney, and Charles A. McDonald, Jr.—E3
Anderson, T. H.—T1
Armenteros, R., B. Gregory, P. Hendel, A. Lagarrigue, L. Leprince-Ringuet, F. Muller, and C. Peyrou—P7
Arnold, J. S.—U7
Arnold, W. H., J. Ballam, A. L. Hodson, R. Ronald Rau, George T. Reynolds, S. B. Treiman, and V. A. van Lint—P8
Asaro, F., F. Stephens, and I. Perlman—G4
Banas, E. M., B. A. Mrowca, and E. Guth—I7
Bandtel, K. C., W. J. Frank, L. Higgins, and B. J. Moyer—L14
Bailey, L. Evan—P3
Barber, W. C.—P9
Barnes, George—H2
Barut, A. O.—O14
Bennett, Arthur and Henry W. Wedaa—C5
Besdin, D. J. and Joseph H. Robinson III—O2
Blois, M. S., Jr.—T4
Bludman, S. A. and D. L. Judd—U8
Boehm, F., P. Marmier, and J. W. M. DuMond—S11
Bond, John W., Jr.—C4, SP1
Bowman, Harry R. and Lloyd G. Mann—P15
Bracewell, Ronald N.—R3
Brady, J. J., M. B. Larson, and T. A. O'Halloran—M8
Brick, R. O., J. J. Brady, and M. D. Pearson—T8
Brown, Frederick C.—H4
Brown, W. W.—P6
Burgess, John C.—D4
Chamberlain, Owen—K3
Ch'en, Shang-Yi, Robert B. Bennett, and Oleg Jefimenko—T5
Christy, R. F.—F1
Colladay, G. S. and S. Barshay—M1
Cork, Bruce—J3
Crasemann, Bernd and D. L. Manley—S1
Crowe, K. M., R. M. Friedman, and H. Motz—L3
Day, R. B., R. L. Mills, J. E. Perry, Jr., and F. Scherb—S4
Dixon, Dwight R. and Kenneth C. Bandtel—E4
Downs, B. W.—D8
Downs, B. W., D. G. Ravenhall, and D. R. Yennie—Q5
Dudziak, Walter, Ryokichi Sagane, and James Vedder—L11
Dyke, W. P., J. P. Barbour, J. K. Trolan, and E. E. Martin—H3
Evans, Marjorie W., Frank I. Given, and William E. Richeson, Jr.—C2
Fairhall, A. W.—P13
Feher, G. and R. A. Levy—I1
Fernbach, S., G. Culler, and N. Sherman—O10
Fleming, John R. and J. J. Lord—L2
Freda, A. R. and G. C. Kuczynski—M5
Friedman, Abraham S. and Irwin Oppenheim—D7
Fuller, Melvin Otis—P1
Fryer, Edward M. and Charles A. Fowler, Jr.—M2
Gardner, Andrew L.—H5
Garrett, C. G. B.—R1
Gasiorowicz, S., M. Newman, and R. Riddell, Jr.—D2
Gell-Mann, M.—B4
George, W., W. Barber, and D. Reagan—P12
Gilbert, F. C.—P4
Glass, R. A., R. J. Carr, J. W. Cobble, and G. T. Seaborg—G8
Gluckstern, Robert L.—P11
Goebel, Charles J.—O7

Goldhaber, Gerson, W. W. Chupp, S. J. Goldsack, J. Lannutti, and F. Webb—L1
Goldsack, Stephen J. and Gerson Goldhaber—U11
Green, G. K.—J2
Grodzins, L.—S5
Guth, Eugene—O11
Hahn, Beat and Robert Hofstadter—Q9
Hahn, E. L. and B. Herzog—I10
Handler, Harry E. and J. Reginald Richardson—S14
Harris, C. W. and E. Guth—O4
Heckrotte, Warren—E8
Heims, S. P., D. R. Yennie, and D. G. Ravenhall—Q6
Hofstadter, R.—Q1
Holder, B. E. and M. P. Klein—I5
Holland, D. H.—O6
Hollander, J. M., and M. I. Kalkstein—G3
Hubbard, Edward L. and Eugene J. Lauer—P10
Hudson, Gilbert G.—H9
Hummel, John P., F. Asaro, and I. Perlman—G6
Hutchison, C. A., Jr.—N3
Jankus, V. Z.—Q10
Jenkins, F. A. and D. R. Speck—T6
Johnson, M. H. and E. Teller—F4
Kaplan, Joseph—R4
Karplus, R. and M. A. Ruderman—F2
Kac, Mark—A2
Katz, Samuel—C7
Kerth, Leroy and Byron L. Youtz—E7
Kip, A. F.—N1
Klein, M. P. and B. E. Holder—I6
Kuczynski, G. C. and M. Doyama—M4
Lagarrigue, A.—B3
Lannutti, Joseph, Gerson Goldhaber, and Stephen J. Goldsack—E1
Levy, R. A.—I2
Lipson, J. and J. H. Reynolds—U5
Livingston, M. S.—J5
Lockary, T. E. and E. Guth—O12
Marmier, P., F. Boehm, and J. W. M. DuMond—S12
Mark, Hans, Clyde McClelland, and Clark Goodman—S3
Marshall, Leona—K1
Mathur, H. B. and E. K. Hyde—G9
Maunsell, C. D.—H7
McCarthy, Kathryn A. and Stanley S. Ballard—M12
McGee, J. F.—U2
McHale, J. L. and R. M. Thaler—O8
Miller, J. M.—G1
Minshall, Stanley—M13
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Oppenheim, Irwin—D6
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—— and R. H. Sands—I12
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Saphir, G.—L9
Schiff, L. I.—Q8
Sells, R. L., C. W. Harris, and E. Guth—O3
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Wildhack, W. A.—U1
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Woodyard, J. R.—U10
Worlock, R. M. and W. R. Smythe—L12
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Yodh, Gaurang B.—L6
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